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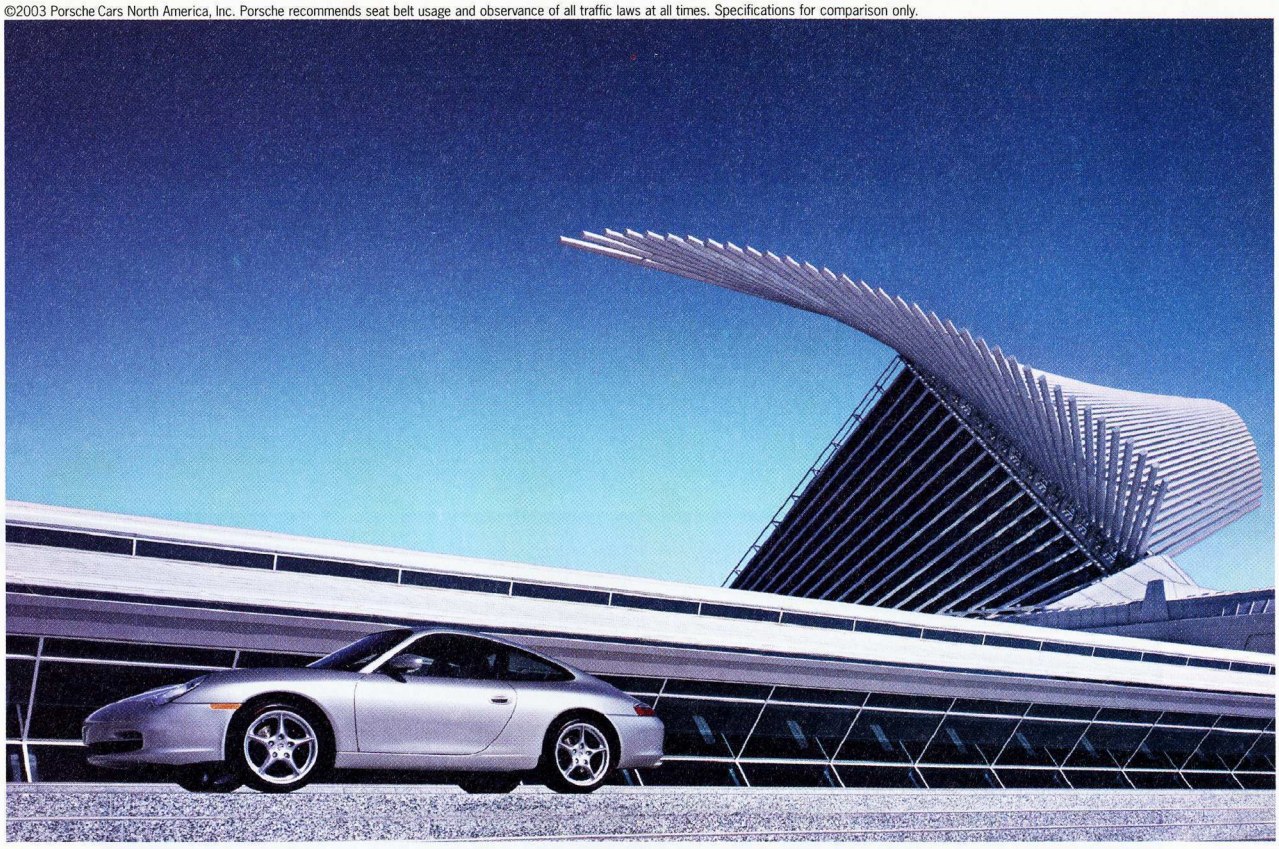
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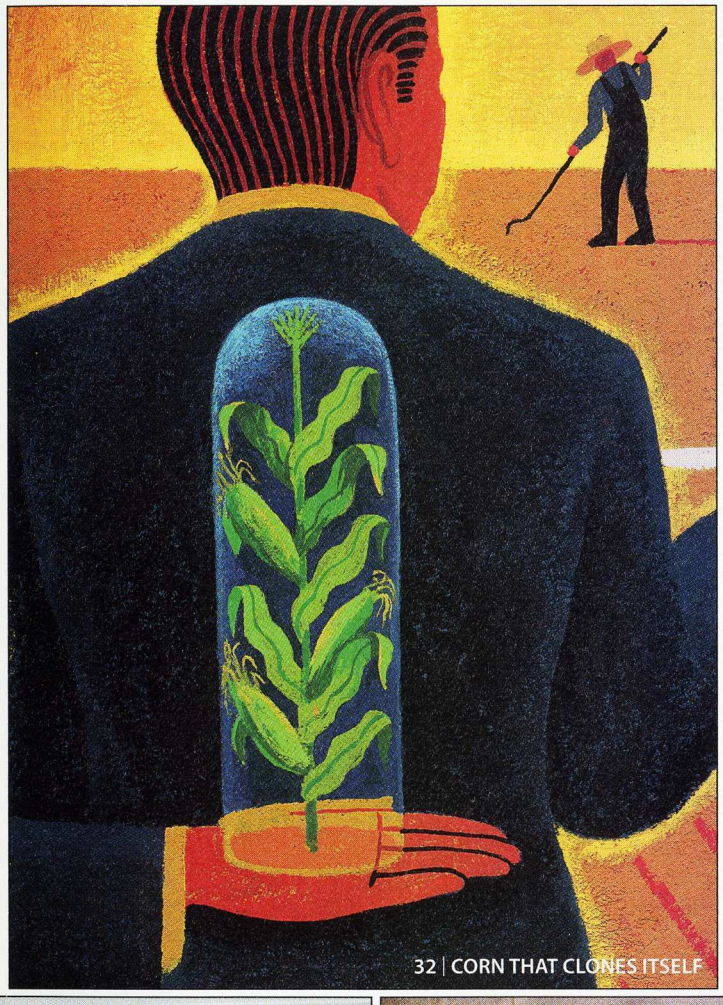
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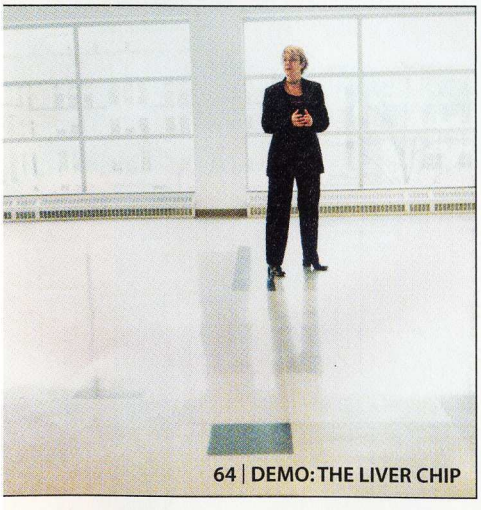
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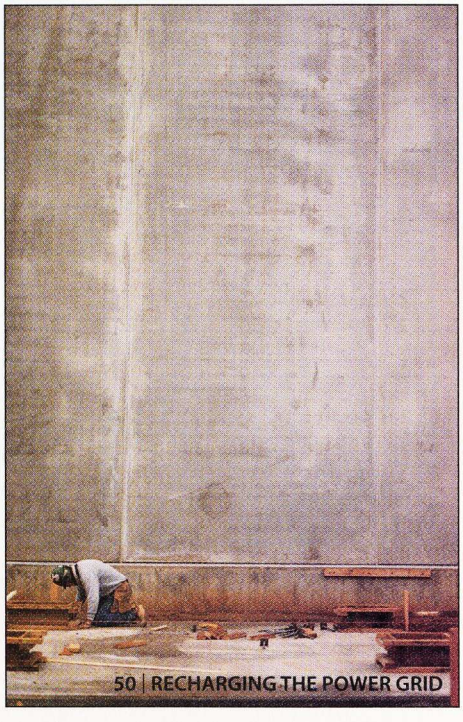


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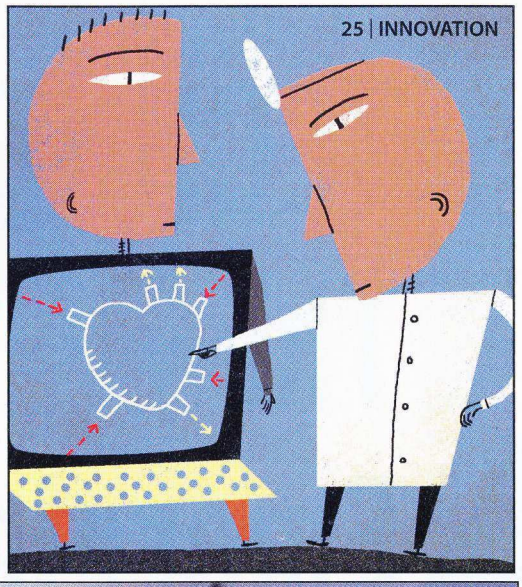
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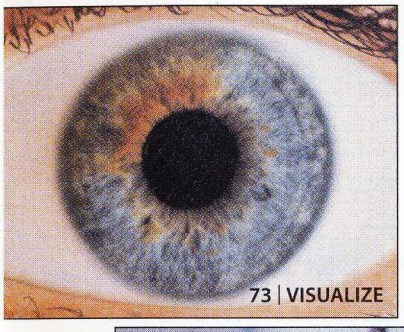
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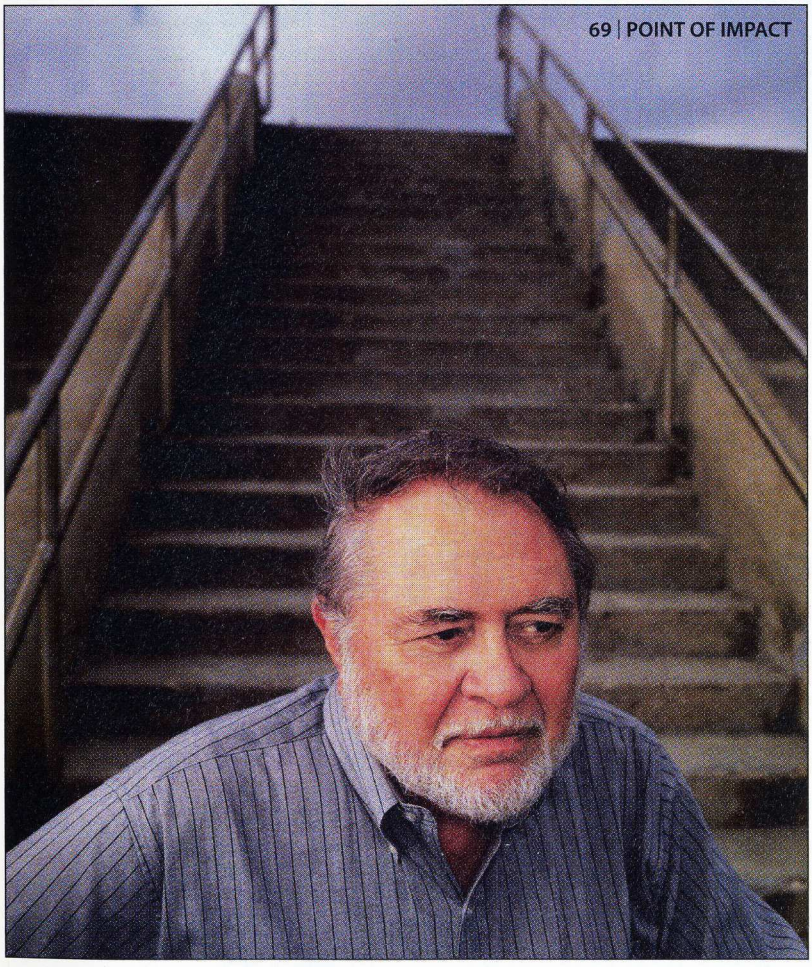
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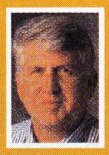
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BE SMART ABOUT MISSILE DEFENSE

On May 13, 1935, a small convoy—two Royal Air Force lorries, a couple of cars, six men—pulled into the seafarers' village of Orford, about 150 kilometers northeast of London. Armed with some crude equipment, the men quickly set up shop in abandoned air force huts. Their secret mission: to save the United Kingdom from air attack. It was almost five years to the day before Hitler's invasion of Western Europe. But their early start developing the technology now known as radar proved critical in warning of approaching bombers in the Battle of Britain—saving thousands of lives and ultimately forcing the Nazis to abort plans to invade Great Britain.

Whenever the debate about U.S. development of a missile defense system heats up—and this month marks the 20th anniversary of the "Star Wars" speech in which Ronald Reagan proposed a system to render nuclear weapons "impotent and obsolete"—I think of Britain's radar pioneers. The analogy is far from perfect. Success for the British meant shooting down a small percentage of enemy bombers; in defending against a nuclear attack, even a 95 percent kill rate could mean atrocious losses. Still, there are striking parallels. Like today's nuclear missile threat, the threat to England in 1935 was vague. Radar then was completely unproved, as is missile defense these days *("Why Missile Defense Won't Work,"* TR *April 2002)*. And like many of today's experts, leading authorities believed an effective defense was not feasible. As former prime minister Stanley Baldwin had famously told the House of Commons, "the bomber will always get through."



Given the stakes, there is no excuse for not pursuing a missile defense system. But how narrow is our definition of missile defense? Will a system be deployed within a smart strategic framework?

So let me be blunt: given the stakes, there can be no excuse for not immediately pushing development of a missile defense system. This is not to say, however, that I wholeheartedly back the Bush administration's program, which might deploy the first elements in Alaska as early as next year. In fact, I don't support this plan, because it appears that certain important issues are not getting proper attention. In particular, two questions must be addressed: How narrow is our definition of missile defense? And, Is the system being deployed on the right scale and within a smart strategic framework?

Let's start with the definition of the problem. The Clinton administration sought to intercept intercontinental ballistic missiles (ICBMs) only in midcourse—after reaching space but before reentry. Many experts, though, back boost phase defense, in which interceptors are deployed from bases or ships near enemy positions to destroy missiles before they reach space. This approach is both cheaper and technically easier, although it raises different geopolitical and logistics issues. The Bush administration, to its credit, has broadened the definition of missile defense and is now pursuing both boost phase and midcourse interception. In fact, its plan is to have as many as four shots instead of one at each enemy missile—a big reason the budget skyrocketed from $5.3 billion to $7.8 billion in fiscal 2002.

So far, so good. But in addition to ICBMs, cruise missiles also pose a potentially huge threat. ICBMs fly high and fast. Cruise missiles fly low and (relatively) slow. Stopping them presents distinct signal-processing challenges and will require radars that look in different directions and likely on different frequencies—and even different or substantially modified antimissile weapons. Yet while we are pouring billions into ICBM defense, the United States is vastly underinvested in cruise missile defense. In fact, says Owen Cote Jr., an associate director of MIT's Security Studies Program, when it comes to cruise missiles, our plans include "no significant defense at all."

Now let's look at deployment. The Alaska-bound system, which targets midcourse interceptions, hasn't come close to proving it can discriminate between real missiles and the decoys that any real attack would almost certainly employ. The main advantage of such a system is that it can defend against missiles launched from almost anywhere, whereas boost phase systems must be deployed in the vicinity of specific threats. But since we aren't facing attacks from almost anywhere, a more reasonable first step would be to deploy boost phase systems around such troubled areas as North Korea and to follow with midcourse systems as we advance the technology. Or, as Cote puts it, "Get in soon on a reasonable scale in a way that's tailored to countering real threats, not imagined ones."

Of course, even a perfect missile-defense system can never make nuclear weapons "obsolete" or guarantee the United States won't be attacked—be it by conventional aircraft or a terrorist operation. But missile defense needs to be pursued. Intelligently. The answer isn't to rush ahead with unproved systems. It's to roll out a defense in phases, at first deploying a limited system comprising technologies that are known to work and adding layers as new elements prove their effectiveness. At the same time, we cannot neglect development of a nationwide system to counter cruise missiles, so that sometime in the next 10 to 20 years we have an integrated, well-tested, comprehensive defense against both types of attack.

Only then will we have a reasonable chance of ensuring that the missile won't get through. —*Robert Buderi*

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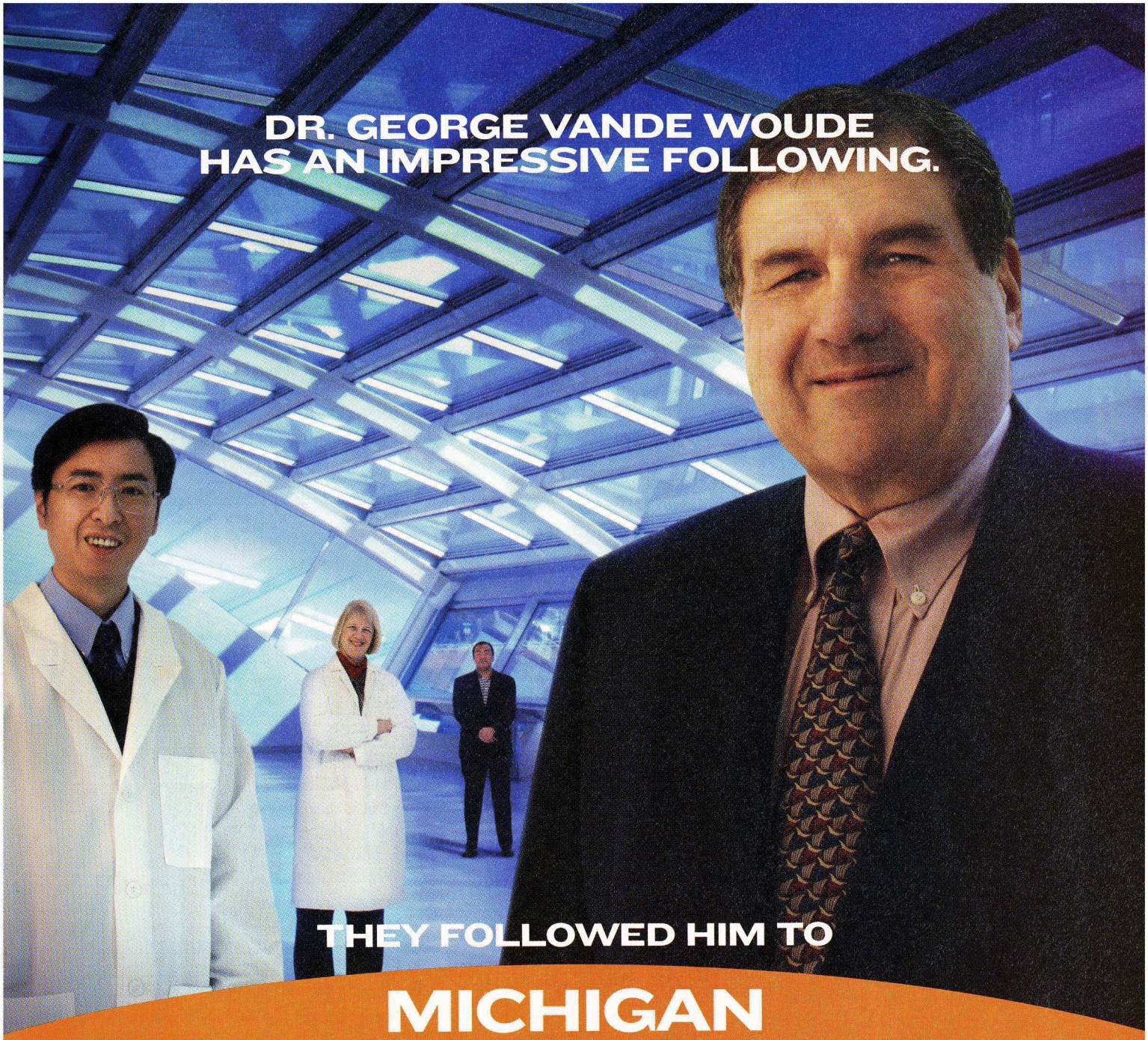
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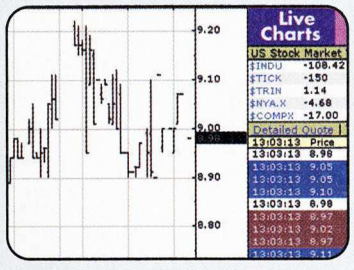
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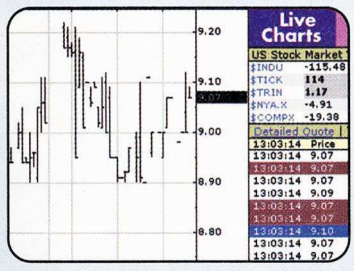
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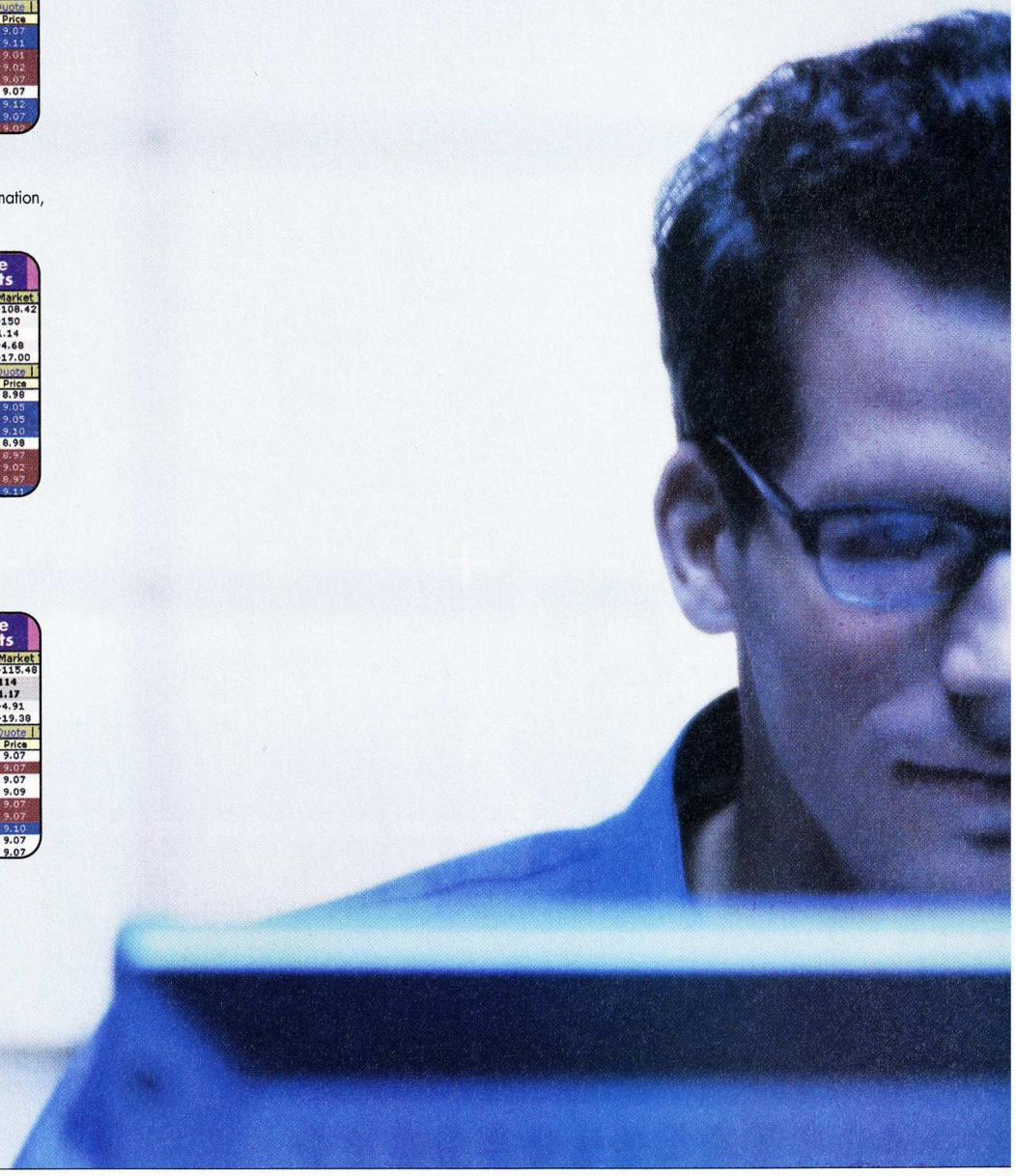
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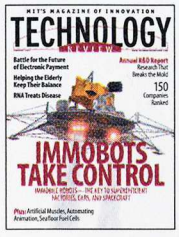
IMMOBOTS TAKE CONTROL

It's interesting that programmers are able to develop systems that think of things that the programmer can't ("Immobots Take Control," *TR* December 2002/January 2003). Or, more precisely, things that the programmer *didn't*. And here lies the fundamental barrier to intelligent computing: our reality must be distilled into terms the system can understand, and the frame of reference for that understanding is defined by the model. It's time, however, to put our models on the shelf and do some real thinking.

Michael Schupan
Ottawa, Canada

This is a good article that touches on a deep subject. Clearly, immobots can fail. How far would you trust an immobot driver of your car? Would you fall asleep and let it drive? What if one of the sensors fails and this leads the immobot to incorrectly deduce that the sensor reading is seeing a very low value? Would the immobot incorrectly invoke an emergency procedure, amplifying a minor problem into a major one? Can we countermeasure by adding a second immobot to watch over the first immobot? This quickly leads to a Rube Goldberg tower.

Donald J. Christian
Fremont, CA



The barrier to intelligent computing: reality must be distilled into terms the system can understand. It's time to put our models on the shelf and do some real thinking.

HOW YOU'LL PAY

Your article on electronic payment devices ("How You'll Pay," *TR* December 2002/January 2003) refers to retail checkout lanes with smart card readers that monitor purchasing patterns and offer promotions. The implication seems to be that this invasion of privacy is a good thing. Corporations have incentives to invade our privacy, and they often bend the rules. This doesn't necessarily benefit the people who buy their products.

Jonathan Fisher
Lyme, NH

After reading your interesting article, I still have one critical question: what happens when someone steals your smart card/Speedpass/iButton?

Rolf Karlsson
Warren, MI

R&D 2002: RESEARCH THAT BREAKS THE MOLD

Fuel cells are old news; connecting power sources to the grid is even older news. ("Electricity-Producing Vehicles,"

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TR December 2002/January 2003). The vast hydrogen infrastructure to make all this work is the real news. How does General Motors plan to get the hydrogen to homes so its "fuel cell skateboard" can "supply power to a house or even feed the local electric grid"? Where will the hydrogen in the hydrogen economy come from, and how will it be delivered to where it's needed? And how will all this be cheaper and cleaner than today's sources of electricity?

George W. Braun
Hawthorne, FL

I was amused by your article's prediction that by 2012, cars might be able to deactivate cruise control when passing through a school zone. I appreciate the technical goal, but how many people are zipping through side streets on cruise control anyway? Maybe 10 years from now, schools will be built next to the highway.

John Pilafidis
Newport Beach, CA

SMARTER INBOXES

After reading Simson Garfinkel's column ("Think Outside the Mailbox," *TR* December 2002/January 2003), the single feature I ask of anyone creating the next generation of e-mail applications is the ability to edit my subject headers. I can't count the times I've reread e-mails searching for information because the sender used an inappropriate or blank subject header. If I could rename them I'd be in e-mail heaven.

Conrad Warre
Newton, MA

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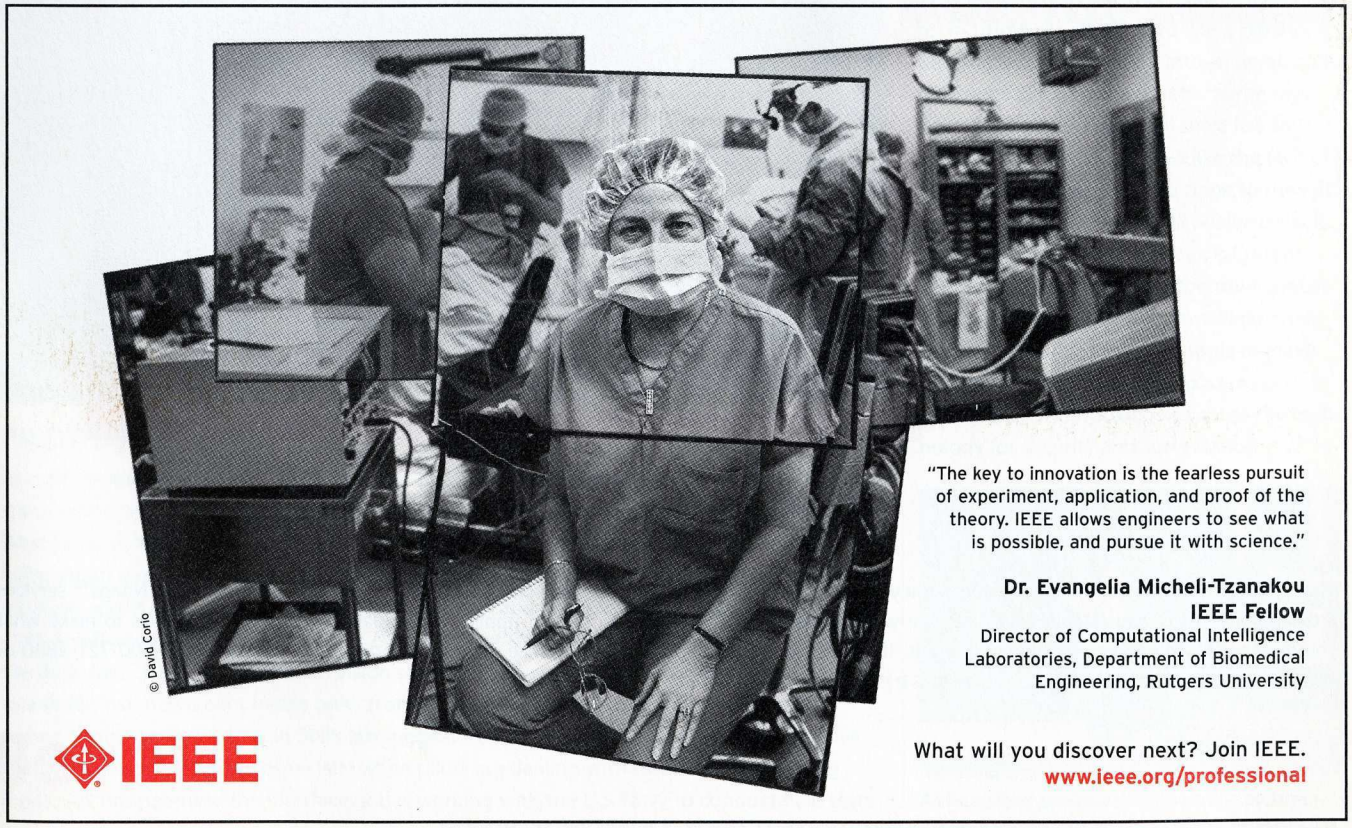
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COMMON SENSE PATENTING?

Seth Shulman suggests that patent rights should be modified on an ad hoc basis to serve the "greater public good" ("A Dose of Common Sense," *TR* December 2002/January 2003). The framers of the U.S. Constitution considered the greater public good when they granted Congress the power to promote the "useful arts" by giving inventors exclusive rights to their creations for a limited time. As Abraham Lincoln later observed, patents add the "fuel of interest" to the "fire of genius."

The "compromise" Shulman urges has been implemented over the past two centuries in the form of U.S. and international patent laws that determine the extent to which "exclusivity" is to be given as an incentive for invention. International patent treaties would be of little use if every country were permitted to mold its own patent systems to fit its own needs.

Richard P. Beem
Chicago, IL





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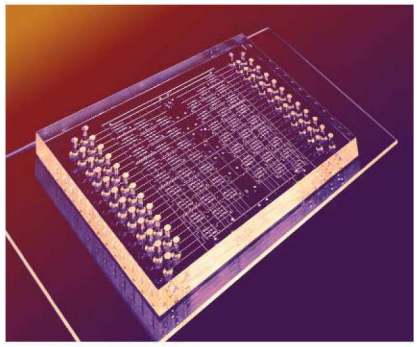
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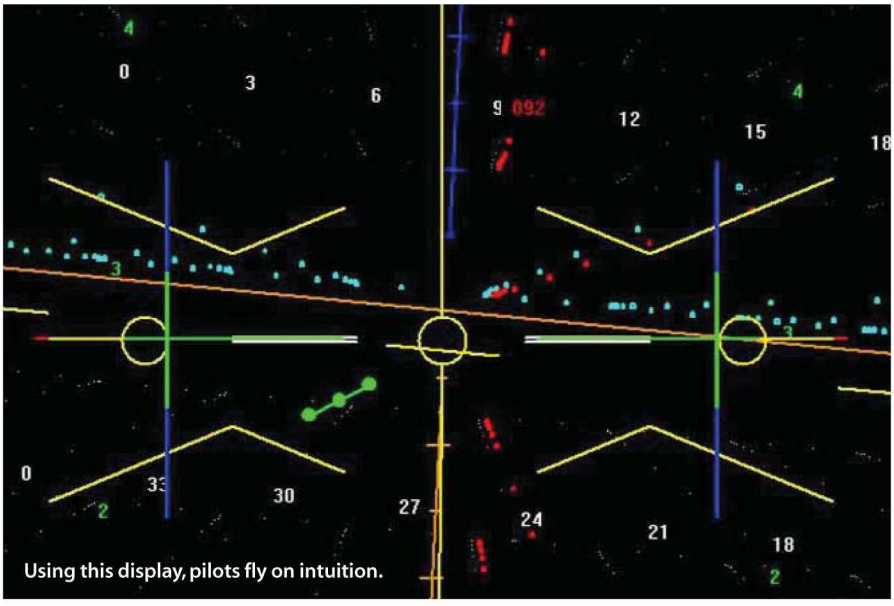
CRYSTAL POWER

Drug makers have a protein problem. Proteins are potential drug targets, but growing a protein crystal—the first step in determining its structure—can take months of trial-and-error experimentation and cost millions of dollars in materials. Fluidigm, a startup in South San Francisco, CA, has developed a chip that allows researchers to grow protein crystals using one-hundredth the amount of the protein, saving money and slashing weeks—even months—off the time needed for this step.



A polymer chip speeds protein analysis.

To get good crystals, biochemists must test hundreds of possible combinations of protein and crystallization reagent: setting up each experiment can take hours, and its success depends on having enough protein on hand. Fluidigm's chip allows simultaneous testing of 144 different crystallization conditions. Using just three microliters of protein sample—a tiny fraction of a drop—the chip diffuses the protein across three distinct concentrations of each of 48 crystallization reagents. Researchers screen the chip for crystals using a microscope; if they find crystals with a particular combination, they can grow more of them and then determine the protein's structure. The company hopes to begin marketing the chips to pharmaceutical and biotech companies early this year.



Using this display, pilots fly on intuition.

PILOT'S PAL

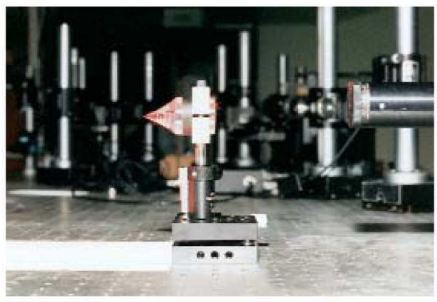
Aircraft cockpits use an array of gauges and dials that pilots read one by one but must understand collectively. A visual interface developed by David Still, a researcher at the University of West Florida's Institute for Human and Machine Cognition in Pensacola, FL, gives pilots all the information they need in a single graphic display. The interface shows the plane's position, orientation, speed, and systems status, as well as the location of runways and approaching aircraft. A software model takes the place of the rules of thumb pilots normally use to process the data, says Still, a pilot trained in vision science. To give the engines the right amount of power, for instance, a pilot needs only to align certain geometrical shapes on the display screen. Flight simulator tests in Still's lab suggest that the system is safer and more effective than conventional displays, especially when pilots are dealing with turbulence or reading maps. Still has patented the interface and is working with the U.S. Navy to conduct field tests.

WOUND MENDER

Scientists at Polyheal, in Nesher, Israel, think microscopic plastic beads could heal chronic foot ulcers and other sores that might otherwise lead to amputation. Polyheal's treatment consists of polystyrene microspheres—each just a few micrometers in diameter—in a vitamin-amino-acid-and-salt mixture patients can spread on their own wounds at home. Company founder and biophysicist Vladimir Ritter stumbled across the beneficial effect of polystyrene microspheres in the course of unrelated research. In early human studies, Polyheal's mixture sped the healing of foot ulcers that had not responded to other treatments. Polyheal has received certification to market the treatment in the European Union, and by midyear it should be ready to publish results of Israeli and German clinical trials. The company is looking for partners for production and worldwide distribution.

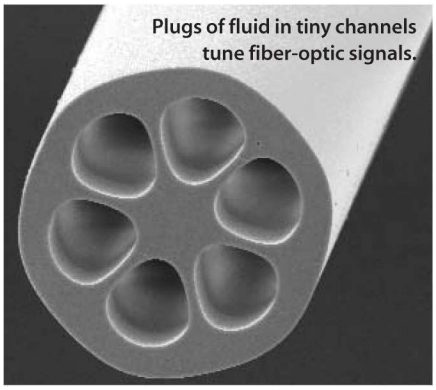
WATCH YOUR BACK

Imagine a periscope that lets you look forward, backward, and all around yourself—without moving. That's possible with an inexpensive lens patented by engineer Jeff Lindner at NASA's Marshall Space Flight Center in Huntsville, AL. Shaped like a Hershey's Kiss, the lens funnels light into a curved compartment that bends and reflects the rays. Point the lens up and you'll see a flat 360° view of the horizon oriented like the face of a clock: straight ahead is six o'clock, to the left is nine o'clock, behind you is twelve o'clock, and to your right is three o'clock. Current panoramic lenses require expensive optical-grade glass. But Lindner uses ordinary polymers and standard machine tools to make his lens, so it should be cheap to mass-produce. NASA is looking to license the technology for security and surveillance.



A cheap lens produces a panoramic picture.

COURTESY OF NASA MARSHALL SPACE FLIGHT CENTER (WATCH YOUR BACK); COURTESY OF INSTITUTE FOR HUMAN AND MACHINE COGNITION (PILOT'S PAL); COURTESY OF FLUIDIGM (CRYSTAL POWER)



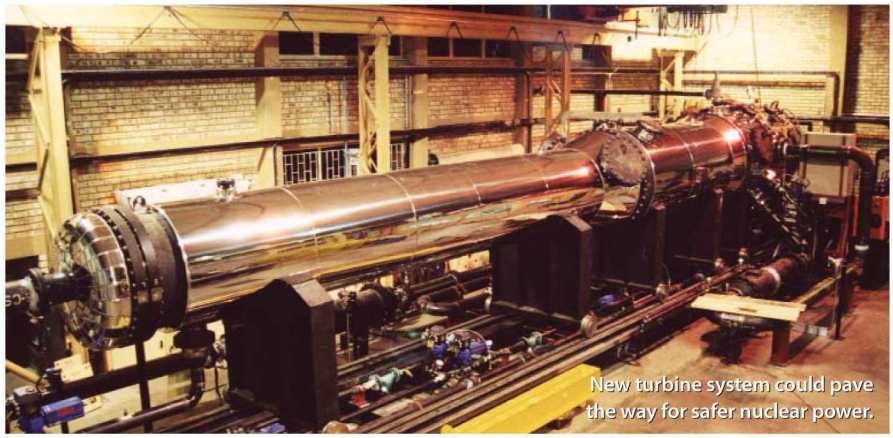
Plugs of fluid in tiny channels tune fiber-optic signals.

FLUID OPTICS

OFS, a Lucent Technologies spinoff headquartered in Norcross, GA, is looking for a liquid solution to the problem of building a better Internet. Researchers at OFS have created experimental optical fibers that employ small plugs of fluid in channels surrounding the light-guiding glass core. Moving a plug along the fiber "tunes" the optical signal on the basis of how the light in the fiber's core interacts with the fluid. Benjamin Eggleton, who until recently headed photonics devices research at OFS, says that such fibers could direct optical signals toward their destination, sending one stream of data from Houston to Kalamazoo, for example, and another to New York City. Achieving an all-optical—and much faster—Internet requires the ability to switch information as light, rather than having to convert data into electronic form and then back to light. But Eggleton, now a professor at the University of Sydney in Australia, cautions that such switches are "a number of years away from practical application."

AUTONOMOUS CHAIR

Motorized wheelchairs grant many people mobility, but they're of little use to those unable to manipulate a joystick or controller. A new wheelchair that navigates on its own could help such people get around. Engineers Steven Skaar of the University of Notre Dame and Linda Fehr of the Edward Hines Jr. Veterans Administration Hospital in Hines, IL, developed the chair using off-the-shelf parts. Skaar and Fehr outfitted a motorized wheelchair with two video cameras, a pair of wheel rotation sensors, and a laptop computer. As a caretaker pushes the chair along a route—from the kitchen to the study, say—its cameras track small elliptical markers on the wall. The team's software uses that information, along with data from the sensors, to record the route. Once the chair has been programmed, the user can choose a route from a menu by speaking, moving an eyebrow, or making some other simple motion; the chair will automatically travel the path. In initial tests, Fehr says, a volunteer who had been pushed in his wheelchair for 30 years mastered the system in minutes. The team hopes to start recruiting for larger tests in the next six months.



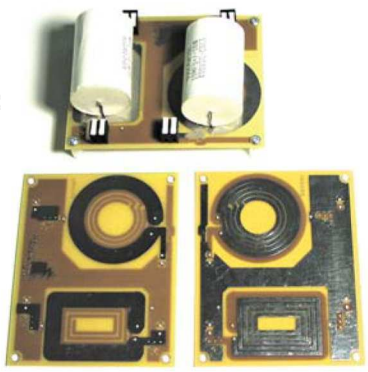
New turbine system could pave the way for safer nuclear power.

HOT HELIUM HANDLER

Pebble-bed nuclear power plants, which would be cooled by helium gas and powered by uranium encased in graphite spheres, could provide safer nuclear power. One significant roadblock to the adoption of the pebble-bed reactor is the requirement of its superheated helium gas for a far more complex gas-turbine system than is needed by today's nuclear plants, which produce much cooler steam. Potchefstroom University in South Africa has made the world's first successful prototype of such a turbine system. Potchefstroom engineers built a 15-meter-long apparatus that, says lead engineer Gideon Greyvenstein, allows expansion of superheated gas directly from the reactor and compresses it for the return trip, tolerates temperatures of 700°C, and includes novel control systems. The engineers developed modeling software to manage such critical operational concerns as overall system pressure. Building a full-blown pebble-bed plant requires decisions from South Africa's government, as well as Eskom, the state utility, and its industrial partners. Those approvals could be granted within a year.

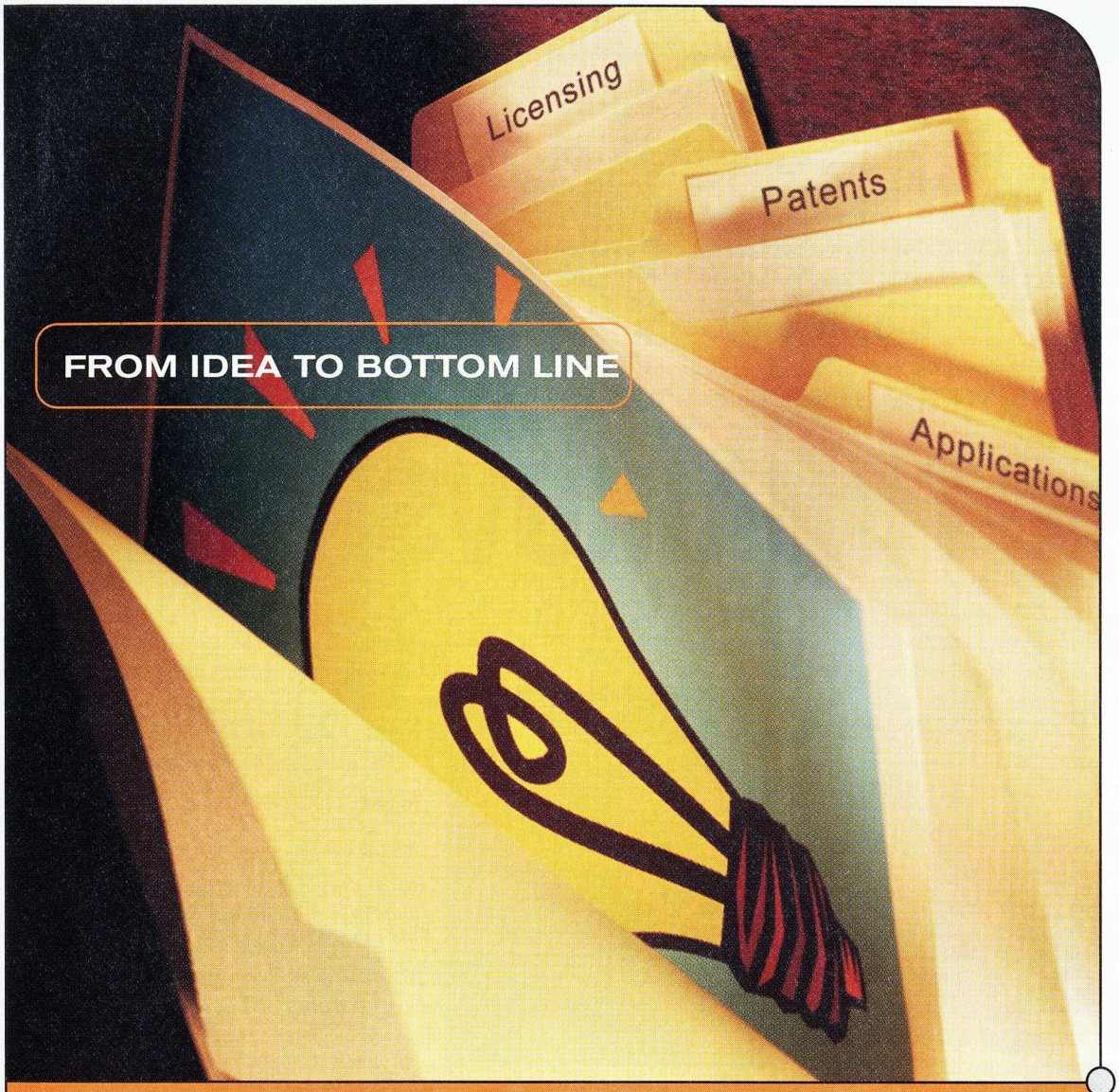
FUZZ BUSTER

The days of fuzzy television may be numbered. Often this annoyance is the result of electromagnetic fields generated by other equipment, say, a vacuum cleaner that shares the circuit with the TV. Banishing the problem entirely would require prohibitively large and expensive versions of devices called filter capacitors. But MIT electrical engineer David Perreault and his colleagues have found a better way to fix TV fuzz and such similar problems as cell phone and car radio static. The approach calls for printing patterns of copper on the circuit boards that carry the filter capacitors. These patterns, called coupled magnetic windings, enhance the performance of the capacitors by generating a tiny voltage from magnetic fields associated with currents in the circuit. The voltage forces the currents to pass through the capacitor for filtering. The payoff: filtering that is 10 to 30 times more effective. And because the copper can be included in the standard manufacturing process at no added cost, "you get something for nothing," says Perreault, who expects the technology to be commercialized within two years.



Copper windings help foil TV fuzz.

COURTESY OF DAVID PERREAULT (FUZZ BUSTER); COURTESY OF POTCHEFSTROOM UNIVERSITY (HOT HELIUM HANDLER); COURTESY OF OFS AND BELL LABS (FLUID OPTICS)



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THERE'S NOT ENOUGH ART IN OUR SCHOOLS.

NO WONDER PEOPLE SAY "GESUNDHEIT" WHEN YOU SAY

"TCHAIKOVSKY."

If one were to make a quick list of the world's favorite composers, despite his relatively recent vintage Peter Ilyich Tchaikovsky would be on it. After all, he did compose *Swan Lake*, which is perhaps the most famous ballet of all time. And there can't be more than just a handful of ballet companies that don't perform *The Nutcracker* every Christmas.

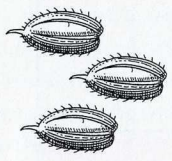


Fig. 1 Pollen

Causes watery eyes. Much like Tchaikovsky's composition "Romeo and Juliet."

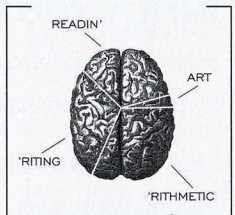


Peter Ilyich Tchaikovsky endured many setbacks, not the least of which was a blind barber.

Indeed, this great Romantic composer should be so immortalized. As a young man, he pursued a career in music at enormous personal risk and against his own father's advice. His mild temperament combined with his tendency to work too hard left him with insomnia, debilitating headaches and hallucinations. On top of that, Tchaikovsky's composition teacher never liked his work, even after he became world-famous.

Setbacks like these could have finished a lesser man. Instead, they informed his work, which remains some of the best loved in history. Yet some kids will still confuse Tchaikovsky with a nasal spasm.

Why? Because the arts are slowly but surely being eliminated from today's schools, even though a majority of the parents believe music and drama and dance and art make their children better students and better people.



Someone isn't getting their recommended daily allowance of art.

To help reverse this disturbing trend, or for more information about all the many benefits of arts education, visit us at AmericansForTheArts.org. Or else Tchaikovsky could seem like just another casualty of allergy season.

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FLAMING IDEAS

You are a fool. You are a moron. Nothing you write is worth reading. Please go away and contemplate just how stupid you really are.

That's neither my opinion of *Technology Review*'s readers nor the feedback I get from writing these columns. But those comments fairly represent the disgraceful level of discourse at such online publications as salon.com, slate.msn.com, and nytimes.com. Talk about lucrative opportunities missed. Talk about failed innovation. Talk about misunderstanding a medium.

The *New York Times*, for example, may be a superbly edited newspaper, but it has a horribly moderated online forum. The *Times* publishes a dazzling array of Pulitzer Prize–winning columnists and invites registered readers to respond online. It's a tantalizing proposition. What policy wonk wouldn't want to post a clever rejoinder to a provocative column by Thomas L. Friedman or William Safire?



I can easily imagine the *Times*' online op-ed forums becoming the well to which the global intelligentsia come for their daily drink of conventional wisdom. Numerous think tanks, foundations, and public relations firms might cheerfully pay a premium to post their takes on what the newspaper of record declares the hot topics of the day. The site could build both the brand and the business and could prove a profitable complement to the paper. It hasn't happened.

More often than not, the postings that appear under the *New York Times* digital brand embarrass more than they enlighten. The logic and the language of the postings range from the infantile to the puerile. This state of affairs is sadly true for a host of other online forums that represent high-quality publications. Why? Apparently, these publications care more about editing online text than facilitating online conversations. They treat customers like *readers* rather than potential *participants*. Anyone schooled in economics is familiar with Gresham's Law: bad money drives out good. Well, indifferent moderating invites a Gresham's Law of Online Interaction: idiotic postings drive away contributors who have something interesting to say. The conversational currency is debauched, and that, in turn, is fueling the popularity of weblogs. Who wants to slog through screens of drivel in hopes of finding one or two worthwhile postings when some of the smartest and most coherent posters host excellent sites of their own?

A company's most valuable assets are its customers. Management's failure to appreciate that—and cultivate customers' appreciation of the company—is a sure sign of laziness. If the *New York Times*—or Dell, IBM, or Pfizer—wanted to be a little less lazy about making sure its customers remain assets, it would pay more attention to the ways other organizations manage online interaction to their advantage.

Say the *Times* cleaned up its online discussions and raised the tenor of conversation. More readers would participate in the online dialogue. And should advertisers sponsor the discussions, the online participants would become more valuable to the *Times* than they are as passive readers. From a branding standpoint, the *New York Times* could transform its online forums into the eBay of elite opinions.

Many online forums already strive to improve the quality of discourse. In particular, the community that has grown up around the open-source software movement—which includes information technology professionals, geek hobbyists, and more than a few *Star Trek* fans who contribute to such sites as slashdot.org—does a far better job of online facilitation and interaction than do the nation's top newspapers and online publications. According to Siobhan O'Mahony, a professor at the Harvard Business School, the open-source community "has been dealing with how to create forums for constructive online dialogue for the past 10 years. And if it can find solutions to this problem, then anyone can."

Apparently, publications care more about editing online text than facilitating online conversations. Talk about lucrative opportunities missed. Talk about misunderstanding a medium.

This community understands how to use its skills to turn readers and posters into design collaborators who can create value where none existed. These forums employ techniques that boost the chances for innovative interactions. "Hackers may have more experience than we do," O'Mahony says, "but there is no reason why mainstream companies can't learn from them."

The most advanced sites use software to control the process. Some systematically rank contributors according to their posting history. Some let readers score each posting, so the highest-rated messages automatically move to the top. In some cases, a community's most trusted participants become de facto editors who weed out unsavory contributions.

To be sure, the open-source community has its own brand of flaming. "You will never have a perfect system," O'Mahony acknowledges. "You might get the occasional 'read the f___ing manual' comment, but in these environments, it is more likely to be sanctioned."

Innovators who value customers' interaction know that the business acronym CRM needs to stand not only for customer relationship management but also for *community* relationship management. Furthermore, they know there is no better place to look for insights into interaction management than among the open-source initiatives running worldwide. Innovators who don't know these facts should reread the first paragraph of this column.

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Semiconductor Innovation LETTER



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1/20/03

TECHNOLOGY REVIEW | VENTUREWIRE
Semiconductor Innovation LETTER

VENTURE CAPITAL, RESEARCH, AND OPPORTUNITY

SiGe Semiconductor Stakes Claim For CMOS Alternative

With $42.8 million in new venture funding, Boston-based **SiGe Semiconductor** won a round for the silicon-germanium camp last week in the ongoing competition with CMOS supporters. The firm, which develops analog and mixed-signal ICs for wireless communications, has centered its technology on silicon-germanium, which proponents say provides higher power efficiency, lower consumption, and better temperature properties than standard silicon.

Since SiGe (www.sige.com) released its first product, a Bluetooth power amplifier, last year, the startup has captured 55% of the global market. **Infineon**, **Maxim**, and others also make power amplifiers, but SiGe claims its amplifiers get more power to the antenna—23 dBm compared to 20 or 21 dBm from SiGe's competitors. The startup attributes its success with the power amplifier to the fact that it receives preferential treatment from fabs because of a longer history of working together, and better prices from them because of SiGe's dominant market position.

But the six-year-old firm isn't placing all its bets on its successful first product and has launched three additional product lines. "What's good about our strategy is that as long as we're achieving success in a number of the markets, we're not risking the success of the company," says Steve Bower, chief financial officer. SiGe also makes cable tuners and has snagged **Arris**, which has more than half of the proprietary cable telephony market in the United States, as a customer. Unlike the

CONTINUED ON PAGE 2

Fast, Cheap, and Flexible

R&D ANALYSIS The world of customizable chips is dominated by ASICs and field programmable gate arrays. Both have big drawbacks. Hybrid approaches could be the answer. And Mathstar—led by serial entrepreneur Doug Pihl—may have the edge with its "silicon objects" technology.

Three years ago Doug Pihl jumped into the same dilemma that faces most semiconductor company executives that want to bring out a new chip: application specific integrated circuits, or ASICs, operate at high speeds and are cheap to manufacture, but their up-front costs can easily exceed $5 million for a chip that might have a market life of a year or two. That's an especially unpleasant prospect in today's tight venture capital climate. The main option has been the field-programmable gate arrays (FPGA), which entail lower up-front costs but suffer from their own drawbacks. They typically run at a maximum speed of 200 megahertz, compared to the gigahertz speeds of ASICs. Moreover, the unit costs of the FPGAs, with their far less efficient use of silicon real estate, can be as much as 40 times higher than the $25-or-so cost of a typical ASIC. So Pihl (pronounced "peel") came up with a hybrid approach.

He had noted that mathematicians had designed sophisticated signal-processing software capable of vastly improving a wide range of applications ranging from image processing to voice recognition. Unfortunately, these programs were extremely complex—so complex, in fact, that it took a supercomputer to run them. Pihl's idea: Develop software that could convert these programs directly to chip-style logic, and then produce the programs as chips. To that end, Pihl founded Minneapolis-based **Mathstar** in 1997 and was soon making significant progress in generating the logic. "I naively thought that building the chip would be the easy part," he says.

It wasn't. By 2000, Pihl realized he had to choose between the staggering up-front costs of ASICs or the poor performance and high unit costs of FPGAs. Might there be a hybrid approach that filled the bill? In exploring that question, Pihl realized he was onto something that could be bigger than the signal-processing

CONTINUED ON PAGE 7

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PHILIPPE WEISBECKER

TAMING TRAFFIC

New projects attempt to predict congestion and help drivers steer clear

Even when they are on roads equipped with advanced traffic-data-collection and advisory systems, drivers know that a fender bender can turn the morning rush hour into an endless wait. Transportation researchers at the National University of Singapore say that although they can't prevent crashes or rubbernecking, they'll soon have a better way to disperse traffic and avoid jams: computers will identify the best response and change electronic highway signs to suggest alternate routes, for instance. The Singapore project is just one of several traffic-prediction efforts that, by 2004, could be saving drivers' time in cities such as Tokyo, Los Angeles, Houston, and Stockholm, where "intelligent highway" infrastructures are already in place.

In these and many other cities, cameras, magnetic loops in roadbeds, and even signal patterns from drivers' cell phones provide analysts with raw data on traffic speed and density. But today's systems for utilizing those data have two big shortcomings: When gridlock sets in, the responsibility for interpreting the data and recommending responses falls to human traffic managers, who sometimes err. Furthermore, their recommendations offer no look ahead. "Without good predictions, you cannot come up with good traffic management," says Henry Lieu, a transportation engineer at the Federal Highway Administration's research labs in McLean, VA.

The Singapore system aims to provide traffic predictions early enough for drivers to act on them. In the aftermath of an accident, the system analyzes traffic conditions in the surrounding area to determine which response—lane closures, light cycle adjustments, or driver advisories—will restore order fastest. The problem is so complex that most computers can't keep up, but the Singapore team has developed efficient algorithms and data-mining strategies that generate predictions and select the best response within seconds. "The system will pick the highest-performance strategy, so you can implement that traffic control strategy on the real traffic network," says Der-Horng Lee, a civil engineer who led the project at the National University of Singapore. His country expects to deploy the system on its 300 kilometers of expressways by August 2005, he says.

A similar traffic-prediction system under development at MIT incorporates feedback—the response of drivers to announcements of anticipated points of congestion. Traffic centers in Los Angeles and McLean plan to implement the program in 2004. Such systems will add intelligence to the roadways—although researchers still haven't figured out how to add any to drivers.—*David Talbot*



SIMULATING SURGERY

Software aims for safer bypass operations

MEDICINE | Vascular surgeons plan most arterial bypass grafts on the basis of experience and intuition: only after surgery is there a way to tell whether an artery has been grafted to the place best suited to restore blood flow with minimal complications. But a group led by Charles Taylor, a Stanford University mechanical engineer who studies the human vascular system, is proving the power of an experimental software system that lets surgeons "sketch" several possibilities and preview the likely results before making a single incision.

The process starts with the collection of three-dimensional nuclear magnetic resonance data that describe the patient's anatomy—the exact shape of the coronary or carotid arteries, for instance—along with snapshots of blood flow at various points. Taylor's software converts the anatomical data into a numerical "mesh" that represents the vessels, and surgeons use computer-aided design to add hypothetical bypass grafts to the mesh. Next, a supercomputer applies fluid dynamics equations to the original flow data, producing a color-coded simulation of blood coursing through the newly configured mesh. By using the simulations to test a variety of graft placements, surgeons can plan operations that don't inadvertently create areas of low blood flow, a cause of clotting that can lead to heart attacks and strokes.

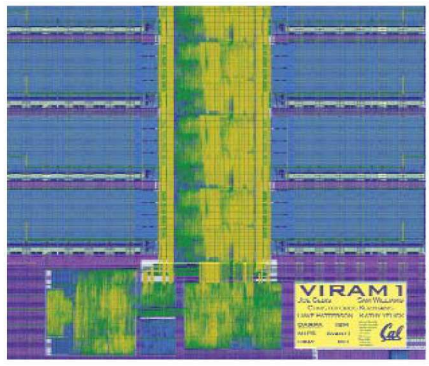
In retrospective comparisons of data from two human patients who received bypasses in their lower extremities, the system's suggested predictions "probably would have changed how the procedures were performed," says Taylor, who hopes that within five years he'll have made the simulations fast and reliable enough for regular use in surgical planning. He says that "10 or 20 years from now every single [cardiovascular] patient is going to be treated this way." —*Wade Roush*

MOBILE MARVEL

HARDWARE | Imagine a Nintendo Game Boy with the gee-whiz graphics of a Sony PlayStation 2 console. That's one of the visions that inspired a team at the University of California, Berkeley, to design a new microprocessor that puts the capabilities of chips found in game consoles and personal computers into battery-powered handheld devices.

Berkeley computer scientists David Patterson, Kathy Yelick, and their students combined several unusual features for their Vector Intelligent Random Access Memory chip. The researchers placed transistors dedicated to short-term memory along with the processor on a single chip: that's a departure from the typical microprocessor arrangement that has most memory on separate chips. This change alone reduces the chip's power consumption to less than one-twelfth that of the processors inside most PCs and laptops. The Berkeley researchers also wrote a program that breaks the repetitive instructions involved in video processing into chunks that can be processed in parallel. Finally, the researchers tailored the chip around a single task: processing 30 frames per second of video data. This simplified its wiring and made the chip cheaper to manufacture than previous memory-in-processor chips.

IBM volunteered to fabricate the first batch of prototype chips, which are being tested now. Dean McCarron, principal at Mercury Research, a semiconductor research firm in Cave Creek, AZ, says the Berkeley group's "unique" approach offers "a subtle way to get more processing" out of a low-power chip. —*Michael Fitzgerald*



The Berkeley chip, shown magnified, expands handhelds' capabilities.

COURTESY OF UNIVERSITY OF CALIFORNIA, BERKELEY (MOBILE); JAMES YANG (ILLUSTRATION)



Illustration shows NASA's conception of a shape-shifting robot plane.

COURTESY OF NASA LANGLEY RESEARCH CENTER (AIRCRAFT)

RESHAPING AIRCRAFT

TRANSPORTATION | Flight engineers have always looked to nature for inspiration. Now they're taking an even closer look. Using materials and computer systems that automatically sense and respond to their environments, scientists at a NASA-funded Texas research consortium are building components for dramatically experimental aircraft. The new planes and spacecraft will be stronger and lighter; they also will be able to "heal" damage to their systems, make themselves more aerodynamic under shifting conditions, and even morph their wing shapes during flight.

About 30 researchers at six universities are being funded through the new Texas Institute for Intelligent Bio-Nano Materials and Structures for Aerospace Vehicles, headquartered at Texas A&M University in College Station. "The challenge is really can we mimic nature," says Satish Nagarajaiah, a Rice University civil engineer involved in the project. To create aircraft that perform more like insects and birds, the researchers will develop composite materials that incorporate organic and biological molecules for use in structural materials, sensors, and actuators. Such control surfaces as flaps, which have been used for decades, could be replaced by wings that continuously morph to maximize aerodynamics and consume less fuel.

The institute's functionalized-nanomaterials group, for instance, is modifying carbon nanotubes—pipelike carbon molecules with unusual structural and electronic properties—to create a "skin" for advanced aircraft, says group leader Enrique Barrera, a Rice University mechanical engineer. The outer layer will be sensitive to changes in airflow and mechanical stress; and it will use the carbon nanotubes as tiny actuators to help the machines modify their shapes in response to changing aerodynamic conditions.

In addition to developing the materials, the institute's researchers will have to create entirely new methods for controlling the vehicles. Today's pilots adjust the positions of such surfaces as flaps and rudders, but the new planes will change their shapes completely and may have 100 times as many sensors and actuators, predicts David Zimmerman, a University of Houston mechanical engineer who heads the institute's intelligent-systems group. "The theory for handling that just doesn't exist today," he says. So his group is developing new control algorithms that will allow a plane to "decide" what shape to assume on the basis of input from its sensors.

Although it may take 15 years to build an aircraft with the ability to reshape itself in response to its environment, structural and sensing components created by the consortium may make their way into spacecraft and the International Space Station in just two to three years, Barrera says. "NASA certainly has put a lot of effort into this," says Rick Claus, an electrical engineer at Virginia Polytechnic Institute and a former NASA engineer. But coming up with improved materials with the characteristics needed to achieve the institute's goals, he cautions, "is going to be a difficult thing." —*Erika Jonietz*

DOLLARS FOR ANTITERRORISM R&D

POLICY | **The attacks of September 11, 2001, prompted calls for large increases in government spending on counterterrorism research. Apparently, Congress and the Bush administration were listening. The three agencies listed here are slated for the biggest boosts in research and development funding in fiscal year 2003, with much of the new money going toward better technology for thwarting and responding to terrorist attacks.**

Of the three, the Department of Defense comes out on top. It will see an additional $9.1 billion appropriated for R&D over last year's $49.6 billion. The 18.4 percent increase is the largest the department has ever seen. —*Tracy Staedter*

R&D Budget (in millions of dollars)

DEPARTMENT	FY 2002 BUDGET ESTIMATE	FY 2003 PRESIDENT BUSH'S REQUESTED BUDGET	FY 2003 SENATE APPROVED BUDGET	FY 2003 HOUSE APPROVED BUDGET
Defense[1]	49,616	54,460	58,764	58,764
Health and Human Services	23,950	27,385	27,578	NA[3]
Homeland Security	0	799[2]	NA[3]	NA[3]

1. Appropriations signed into law on October 23, 2002.
2. Estimated by American Association for the Advancement of Science.
3. Not available: at press time, Congress had not passed final appropriations bills for these agencies.

SOURCE: American Association for the Advancement of Science.



A digital camera atop a Pocket PC grabs text for translation.

SIGN LANGUAGE

Translation software deciphers billboards and street signs

COMPUTING | In our global economy, the ability to understand languages other than one's native tongue grows more important every day. That is why Jie Yang, a computer scientist at Carnegie Mellon University, and his colleagues have created software that reads Chinese signs and quickly translates them into English using nothing more than a palm-size computer equipped with a small camera.

"If you're trying to get somewhere, it helps to be able to understand the signs around you," says Yang, who plans to develop translation modules for Japanese, Arabic, and Korean if funding is available. "There's a growing demand for products like this," he explains.

The seemingly simple task of interpreting street signs actually represents a bundle of problematic processes—from machine vision to character recognition—with which researchers in computer science and artificial intelligence have been struggling for years. Yang chose some of the most promising software solutions and squeezed them into a handheld Pocket PC device. His system starts by scanning an image for hard edges—a sign's borders. Next, it searches for cues such as contrasting, similar-size characters. Optical character recognition software "reads" the words, and other algorithms cluster them into plausible groupings.

Then comes the hard part: the actual translation. "Ambiguity is the biggest problem," says Alex Waibel, director of Carnegie Mellon's Interactive Systems Laboratory, where Yang is based. "Words can have so many different meanings in so many different languages in so many different situations." That's why a device that renders a literal translation can't always do the job. If a Chinese sign meaning "Please do not touch" were translated word for word, for example, it would say, "Please do not move hand."

To deal with such ambiguities, Yang considered three dominant machine-translation approaches, each with its own advantages. One, knowledge-based translation, requires humans to program rules that describe how a language's words relate to one another. Slot Grammar, an IBM version of this approach, would break a sentence such as "John gave Mary a book" into the verb "gave" and three related words that fill slots: a subject (John), a direct object (book), and an indirect object (Mary). The IBM system then uses these relationships to search the knowledge base for similar relationships in the target language, and those relationships help generate a sensible translation.

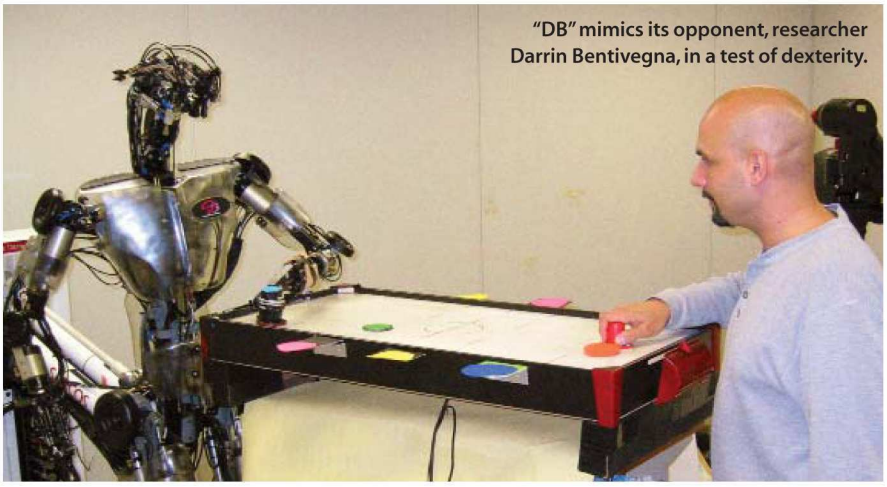
At Microsoft Research in Redmond, WA, scientists rely on an example-based system that taps raw computing power rather than programmed rules. The Microsoft technology compares millions of words and phrases of translated text. Along the way, it generates an enormous bilingual dictionary of word relationships, phrases, and idioms. Then, in a process similar to sentence diagramming, it breaks target text into "logical forms" and finds the best-matching forms among those in the dictionary.

The third approach is statistical. Like Microsoft's approach, it starts by crunching reams of word relationships. But unlike example-based systems, it scores the best translations using a statistical model that identifies the phrases and words in each language that properly match under a variety of circumstances.

Yang tried both the example-based and the statistical approach to see which translator would perform better. Right now, each delivers at least partially accurate translations 82 percent of the time, compared with 70 to 80 percent for most other translation systems, he says. Yang and other researchers agree that combining all three approaches should prove the most promising long-range strategy. "There's no other way we can keep up," says Steve Richardson, head of the machine translation project at Microsoft's Natural Language Processing Group.

The harder researchers push toward 100 percent accuracy, unfortunately, the more stubborn the problem becomes. Machines will "never be as good as humans" at translation, says Yang. But, Waibel adds, they "are getting better all the time." —*Chip Walter*

COURTESY OF JIE YANG



"DB" mimics its opponent, researcher Darrin Bentivegna, in a test of dexterity.

MIRRORING MOTION

Robots gain agility by watching their makers

ROBOTICS | At the Advanced Telecommunications Research Institute in Kyoto, Japan, a million-dollar humanoid robot is learning to play air hockey. Using stereo video cameras, "DB" watches as a researcher strikes the puck with his paddle. Then using its hydraulically powered arm, the robot imitates the motion. After a few false starts, DB is able to hit the puck, and its movements are surprisingly graceful. This sort of "imitation learning" is yielding smarter, more adaptive robots for physical therapy, search-and-rescue missions, and space applications.

Imitation learning combines artificial-intelligence software with cutting-edge neuroscience. To learn arm movements for air hockey—or even for hitting a tennis ball—the robot uses machine vision algorithms to determine the position and velocity of a person's limbs and maps this information to its hydraulic joints. Comparing its own movement with the original, the robot makes adjustments in real time. This is a more efficient way to make a robot perform human tasks than brute-force programming or trial and error, says computer scientist Stefan Schaal of the University of Southern California. Schaal is teaching DB new tricks in collaboration with the Japanese research group, Carnegie Mellon University, and Sarcos, a robotics company in Salt Lake City.

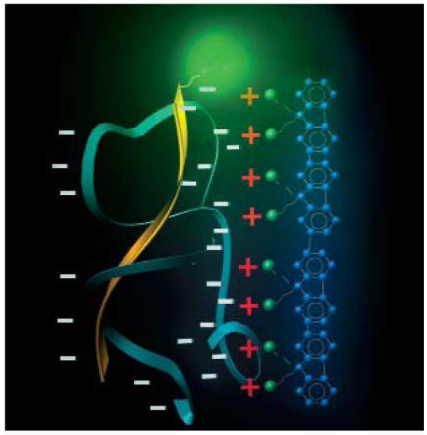
Until recently, however, "there was a large component of Simon Says with these robots. They didn't understand what they were doing," says Carnegie Mellon robotics expert Chris Atkeson. Changing one of their familiar tasks even slightly, in other words, would befuddle the machines. To add flexibility, researchers are now teaching robots to divide movements they've seen before into pieces that serve intermediate goals. Robots can learn to splice these building blocks together to adapt their behaviors—reaching, balancing, and even walking—to new situations. Within a few years, says Schaal, such resourceful robots could perform hazardous rescue missions, analyze stroke patients' movements to help them refine motor skills, and replace space-walking astronauts on repair missions. —*Gregory T. Huang*

BRIGHT LIGHTS, MOLECULAR WORLD

MATERIALS | The glow of fluorescent probes has become a critical lighthouse in biomedicine, serving an essential role in many diagnostic, forensic, pharmaceutical, and genomic screening tests. Currently available tests for early detection of HIV, for example, use a probe molecule—a specific protein combined with a light-emitting molecule—that glows when it encounters the RNA of HIV. The glow is detectable by an optical sensor. Researchers at the University of California, Santa Barbara, have developed a simple way to amplify these signals from the molecular world.

The key is a new class of light-emitting polymers that release their optical energy when they come into contact with the probes, boosting the glow by a factor of 25, says Guillermo Bazan, a materials scientist at Santa Barbara. This amplification could mean far more sensitive tests. In fact, says Bazan, "we can detect lower concentrations of HIV's RNA than any of the optical methods today for direct HIV detection."

Equally important is the potential to reduce costs. Fluorescent probes are expensive, and the Santa Barbara technology could mean much less probe material will be needed for diagnostic tests. The new technology would be welcome in developing countries where many people go untreated simply because HIV tests are too expensive.



New polymer (right) amplifies glow of fluorescent probe (top) binding to HIV's RNA (left).

Applications extend well beyond early detection of HIV. Because fluorescent probes are commonly used to identify specific DNA sequences, light amplification with Bazan's polymers could boost the sensitivity and reduce the cost of procedures ranging from forensic DNA matching to gene tracking in crops. Polymers for brighter fluorescent probes could be ready for genomic research in a year or two, says Bazan, who is working with colleagues to boost fluorescence a hundredfold. Better blood-screening tests and other diagnostics using the polymers could be on the market within three years. —*David Talbot*

COURTESY OF UNIVERSITY OF CALIFORNIA, SANTA BARBARA (BRIGHT LIGHTS); COURTESY OF ATR CYBERHUMAN PROJECT (MIRRORING MOTION)

SIMSON GARFINKEL

THE NET'S FALTERING DEMOCRACY

Critics charge that it is the De Beers of the Internet: an organization that, like the diamond cartel, has created an artificial scarcity to protect a few established players. Worse, they say, whatever claims this body once had to legitimacy were wiped away last year when its board voted to abolish elections.

This faceless power center is the Internet Corporation for Assigned Names and Numbers, or ICANN. And its actions may jeopardize the future of the Internet.

The Internet could evolve into a global commons where people all over the world are free to communicate and interact and to distribute and consume an endless variety of literature and media. Or it could become a tool for enforcing corporate control and governmental censorship. Which direction the Internet takes depends in large part on which policies and technologies ICANN supports.

Many people think the Internet can never be subject to centralized control. Wasn't this global distributed network built to withstand a thermonuclear attack? Doesn't it treat censorship as damage and route around it? So goes popular Net mythology. But in reality, the Internet is a human institution. And like a corporation, nation, or family, it can be led astray.



The company formed to administer Internet domains and addresses was to have the efficiency of private enterprise and the legitimacy of an elected government. This proved to be impossible.

Global communication requires global standards, and it is here that the ICANN has its grip on the system's choke point. This company sets rules that govern the worldwide assignment of all-important domain names. Its rules are incorporated into contracts and passed on to anybody who gets a dot-com, dot-net, dot-org, or dot-info domain. The best-known of these rules is the Uniform Domain Name Dispute Resolution Policy. If you have a top-level domain name, you've agreed to this policy. ICANN's glacial pace for establishing new top-level domains has been a great help to domain registrars such as VeriSign: they profit from the lack of competition. Because there is a limited number of registrars and a limited number of top-level domains, the worldwide domain-name business is directed to the incumbents. The dispute resolution policy creates procedures that can be used to seize a domain name from one organization and hand it to another. This policy has been widely hailed as a boon for trademark holders worldwide.

ICANN's second mode of control is in its ultimate allotment of Internet Protocol addresses—the Internet's equivalent of phone numbers. Theoretically, control of domain names and Internet addresses could be exploited for purposes that range from stifling competition among Internet service providers to shutting down an entire country's access to the Net. Imagine if instead of having to take Napster to court, the recording industry had been able to bypass the courts and shut down Napster simply by nullifying its domain name and addresses.

None of this would be a big deal if we were talking about an international organization whose policymaking machinery was responsive to the needs of Internet users. But that's not the case: ICANN, a private corporation, is chartered by the state of California and answerable to no one. It is an outgrowth of the Clinton administration's attempts to privatize control of the Internet; ICANN's authority comes from a "memorandum of understanding" with the U.S. Department of Commerce. Handed a letter of agreement and a board of directors, the corporation was told to go forth and make policy.

The one attribute the U.S. government couldn't confer on this outfit was legitimacy. The Internet is supposed to be a global resource, so ICANN's original plan called for Internet users worldwide to elect nine at-large directors. Those directors, together with nine other directors appointed by important Internet interest groups, would ultimately craft the policy of the global information infrastructure.

ICANN was designed to have the efficiency of private enterprise, but it was somehow supposed to acquire the legitimacy of an elected government. Alas, this proved to be an impossible task. The election was a flop. Voter registration took place in the summer of 2000. ICANN says 158,000 Internet users—far more than had been expected—tried to register. Only 75,000 of them completed the elaborate verification process, which entailed getting a personal identification number by e-mail and then typing it into a Web site. And in the end, only 34,000 people voted in October 2000. But those numbers actually overstate the level of user participation: in North America, according to Election.com, the company hired to run the election, a mere 3,449 votes were cast. Karl Auerbach, the candidate elected to represent the United States and Canada, received 1,725 of those votes. Although that's a majority, it's an exceedingly tiny fraction of the Internet's user population.

But ICANN need not worry about more sham elections. When the company's board of directors amended its bylaws last December, it eliminated elections and instituted an advisory committee-at-large whose members—chosen by other committees—lack real power. Maybe that's okay. "ICANN is not an experiment in global online democracy," says Stuart Lynn, ICANN's president and CEO. "So the board decided that, at least for now, elections were not to go on."

Perhaps ICANN serves as a model for systematically shutting the public out of messy policy debates and letting the appointed representatives of global business take over.

Perhaps democracy is overrated.

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corn that clones itself

NEW VARIETIES OF GENETICALLY ENGINEERED CROPS WILL FEED THE POOR AND RESTORE AGRICULTURAL BIOTECHNOLOGY'S BLIGHTED IMAGE— IF MONEY AND POLITICS DON'T KEEP THE SEEDS OUT OF FARMERS' HANDS.

BY DANIEL CHARLES • ILLUSTRATIONS BY JAMES STEINBERG

AN HOUR OUTSIDE OF MEXICO City, the taxi turns off the main road, and the noise and bustle of the highway fade away. Past a steel gate and a white guardhouse, we enter the well-tended grounds of the International Center for the Improvement of Maize and Wheat, known by its Spanish acronym, CIMMYT (pronounced SIM-it). It's a farm masquerading as a small United Nations. An array of flags pays tribute to the countries that fund the organization's work: creating better crops for the developing world's poor farmers.

Further ahead is a line of white signs, each standing in front of a small square plot where hairy heads of wheat sway in the breeze. This is agriculture's Walk of Fame; on those signs are the names of wheat varieties that emerged from CIMMYT's breeding grounds four decades ago: Sonora, Yaqui, Kauz, Sujata, Sonalika, and others. These varieties, which resist disease and produce unprecedented yields, conquered Asia, displacing traditional wheat varieties and older methods of farming. The stars of the Green Revolution, the new varieties unleashed a phenomenal rise in grain production that allowed China and India to feed themselves. Indeed, the impact of the new grains was so great that they earned Norman Borlaug, the original director of CIMMYT's wheat program, the Nobel Peace Prize in 1970.

But wait. Isn't this supposed to be the International Center for the Improvement of Maize and Wheat? Maize, as most of the world calls corn, is the second-most widely grown crop after rice; it's a remarkably efficient factory for converting sunlight, soil, and water into food for people and animals. Within the next few years, corn is projected to pass rice and take over the top spot. So where's the corn? Why is it missing from the Walk of Fame?

As anybody who has driven across the Midwest can attest, superior varieties of corn certainly do exist. But the robust, high-yield plants that cover the Iowa countryside are beyond the reach of the majority of the world's poor and subsistence farmers—the very people CIMMYT was founded to help. The problem is, if farmers want to plant those top-of-the-line varieties—generally high-octane hybrids that seed companies create by crossbreeding two distinctly different inbred lines—they have to buy new seed every year. Poor farmers simply can't afford to do that.

The annual requirement for fresh seed is in part a consequence of corn's biological compulsion to mate freely and indiscriminately. Wheat, like rice, practices the safe sex of self-sex. Each flower pollinates itself, producing daughter plants that are nearly exact copies of their parents—at least that's the case with purebred wheat varieties such as those released by CIMMYT. As a result, farmers can use part of each year's harvest for seed, and varieties can easily be shared—passed from field to field, from one farmer to the next.

Corn, on the other hand, is the most promiscuous of plants. Its tassels—the male genitalia—dispense millions of pollen grains into the wind, randomly fertilizing nearby corn ears, the female genitalia. A plant's offspring, therefore, can vary enormously, depending on which pollen wandered into the neighborhood. So no matter how carefully CIMMYT's breeders construct improved varieties of corn, the genetic identity of those lines breaks down quickly when they are released into the genetic melting pot of farmers' fields. The new traits—higher yield, ability to withstand drought, resistance to disease—tend to dissipate and even disappear.

The variability problem is even greater with the hybrid varieties seed companies favor. For corn and even for self-pollinating plants, a hybrid's offspring are nothing like the original.

If only corn could reproduce by skipping pollination altogether and cloning itself. The idea is not as far-fetched as one might think. A few plants do this naturally, creating seeds without sex in a process called apomixis. Dandelions reproduce through apomixis; so do about 400 other plant species, including at least one wild relative of corn. So why not corn? If someone could flip a switch and make corn apomictic, CIMMYT might finally be able to make highly productive hardy strains poor farmers could share with their neighbors and replant from their own harvest year after year.

Richard Jefferson, founder of the Center for the Application of Molecular Biology to International Agriculture in Canberra, Australia, says that the implications of apomixis go well beyond corn. The potential of self-cloning plants, he says, is so profound and subversive that plant breeders, generally a cautious and understated lot, "would never admit to dreaming about it unless you got them drunk first."

In addition to bringing hybrid and other superior varieties of corn within reach of even the poorest farmer, apomixis would allow the widespread use of high-yield hybrid rice, plants whose seeds currently are expensive and difficult to produce in large quantities. And apomixis could help eliminate diseases from cassava, an African staple crop that is grown by replanting pieces of tubers from parent plants, some of which carry disease.

After more than a decade of work, researchers at CIMMYT and a handful of other laboratories around the world are finally homing in on apomixis. With the help of new genomic information and tools, they're tweaking the genes that control plant reproduction, hoping to duplicate the self-cloning process in corn and other important crops. If they succeed—and they seem confident that eventually, perhaps in another decade, they will—apomixis will open the door to a "revolution in world food production," says Wayne Hanna, a geneticist with the U.S. Department of Agriculture in Tifton, GA.

That may seem like a technology goal few could argue with. Yet there's uncertainty about whether apomixis ever will be allowed into farmers' fields. Two opposing forces could find themselves unlikely allies in an effort to block it: political opposition to genetic engineer-

The implications go well beyond corn. The potential of self-cloning plants is so profound and subversive that plant breeders, a cautious and understated lot, would never admit to dreaming about it unless you got them drunk first.



ing and the financial considerations of agricultural companies that are among the primary sponsors of apomixis research.

"A FEW GUYS WERE CRAZY ABOUT apomixis for many years," says Daniel Grimanelli, a young scientist who is already a grizzled veteran of the field. Settled on a patio outside CIMMYT's Applied Biotechnology Center, Grimanelli is taking a midmorning break from science. Judging by his three-day stubble, sunglasses, cigarette, and tattered jacket, Grimanelli might just as plausibly have emerged from a serious bender. Thanks to a joint appointment to CIMMYT and the Institut de Recherche pour le Développement in Montpellier, France, the Frenchman was transplanted to Mexico a decade ago, but he speaks English with eloquence and force.

"In the 1970s and early 1980s," Grimanelli continues, "there were essentially four guys: Yves Savidan in France, Wayne Hanna in Georgia, Victor Sokolov in Russia, and Gian Nogler in Switzerland." Apomixis, in those days, was a botanical curiosity, nothing more. Hanna recalls encountering it in the form of some odd-looking sorghum plants in a Texas greenhouse; Sokolov, far off in the Siberian city Novosibirsk, devoted his labors to gamma grass, a relative of corn; and Savidan, working at that time in Ivory Coast, was handed a selection of wild West African grasses.

All these plants engage in an odd form of reproduction. Their ovaries produce new embryos on their own, as clones of the mother plant. Yet a few of these plants also engage in sex. So the elder statesmen of apomixis studied the patterns by which this particular genetic trait is inherited when apomictic plants mate with their nonapomictic relatives. "We ended up finding that the trait behaved like a single dominant gene," says Savidan, who now directs the international partnerships of Agropolis, a publicly funded research consortium in Montpellier. It was an astounding conclusion, and Grimanelli says, it led to an audacious idea: "If it's that simple, why not put it in crops? Why not crossbreed maize with an apomictic relative? Easy!"

"Easy," echoes Grimanelli's colleague Olivier Leblanc dourly.

Grimanelli and Leblanc represent a link between the early generation of such apomixis researchers as Savidan, who used traditional plant breeding, and a new wave of researchers who employ molecular markers, genomic data, and genetic engineering. Savidan moved his apomixis research to CIMMYT in the late 1980s, and Leblanc and Grimanelli joined him a few years later. It seemed the perfect place. For one thing, CIMMYT's climate-controlled vault full of seed samples held a treasure-trove of seeds from gamma grass, a bushlike plant that is corn's closest apomictic relative. More important, CIMMYT's mission of improving crops for farmers in the developing world squared perfectly with the potential benefits of apomixis.

But a decade of traditional plant breeding yielded only frustration. The researchers tried to crossbreed gamma grass and corn. They produced 300,000 hybrid plants, creations with strange combinations of features of both plants *(see p. 38)*. They tried to backcross those hybrid plants with regular corn, hoping that each generation would bring them closer to an apomictic version of corn. Inevitably, somewhere on the long road toward corn, apomixis disappeared.

But just as the old approach was dying, a new one was born. In 1999 CIMMYT signed an agreement with a French seed company, Limagrain; a division of Swiss pharmaceutical giant Novartis that has since become Syngenta; and the world's largest seed company, Pioneer Hi-Bred. The agreement gave the center funding and access to private corn-genome databases. "The new tools

It's not how many ideas you have. It's how many you make happen.



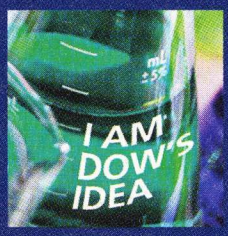
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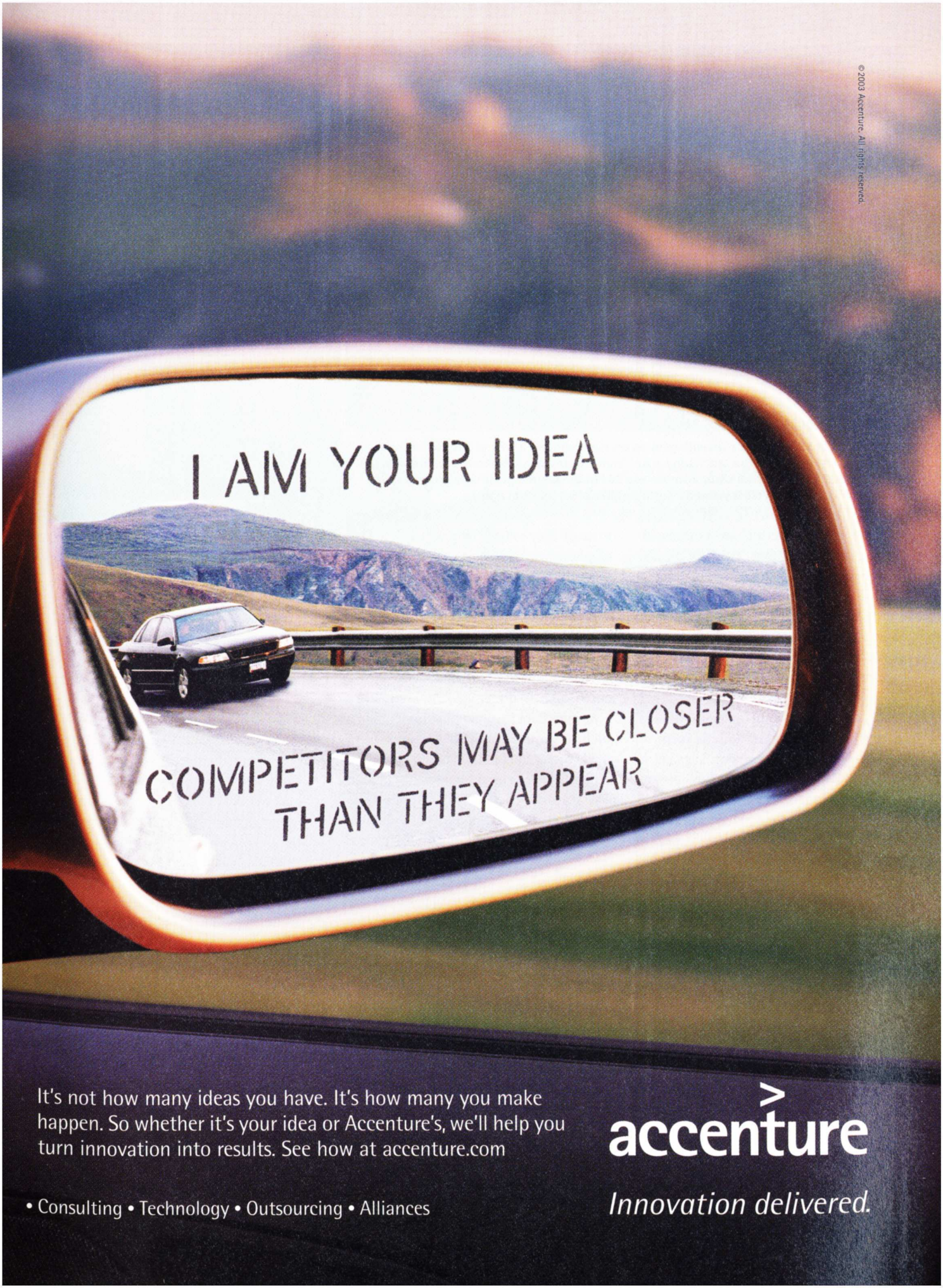
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To develop a sustainable competitive advantage in the global chemical industry, Dow sought to aggressively leverage its investment in information technology, dramatically improving systems productivity and significantly reducing application costs and time to market.

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Crazy corn: CIMMYT crossed corn with gamma grass, generating a host of odd-looking plants (above; gamma grass is in the center). In a plant from an early cross (bottom left), chromosome tests revealed 10 darker corn chromosomes and 36 lighter gamma-grass chromosomes (top right). A more advanced cross yielded a more cornlike plant (bottom right).

have become so powerful," says Grimanelli. "You can clone genes, modify genes, express genes."

He and Leblanc embarked on a search for apomixis genes, sifting through the sections of DNA that were present in the apomictic form of gamma grass but not in the sexual version. They tracked those genes to a large block of DNA, about one-third of a chromosome, that is always present in the apomictic form of gamma grass. To find the specific genes in this huge field of DNA, the researchers are throwing transposons—small bits of DNA that insert themselves randomly into chromosomes—at that block of DNA. They're hoping that the transposons will insert themselves into genes that are important for apomixis, disrupting the process. When that occurs, the researchers should be able to locate the transposon and with it, the crucial gene—which they could then insert into corn.

But the CIMMYT researchers are not alone in their search for the genetic keys to apomixis. A horde of other researchers, some of them sponsored by small biotech startups, have joined the hunt. Competing projects have sprouted in Germany, Switzerland, Australia, the United Kingdom, France, Mexico, California, Texas, and Utah. Most of the newcomers are not hoping to transfer apomixis genes from one species to another—from gamma grass to corn, for instance. Instead, they're tinkering with the timing of plants' own genes to trick them into reproducing without fertilization. The researchers are working out the details of this "synthetic" apomixis through experiments with their favorite "lab rat," a small mustard plant called *Arabidopsis thaliana*.

The CIMMYT researchers, whose effort also is going to rely heavily on genomics data from better-known plants such as *Arabidopsis*, say the leap from *Arabidopsis* to corn is likely to be more difficult than many researchers expect. But still, they say, it will happen. The "incredible dynamism of so many people working on this," says Grimanelli, will not be denied.

THE LEAP FROM LABORATORY TO field appears, however, equally daunting these days. An apomictic corn plant will be a genetically modified organism, and in much of the world, such organisms aren't welcome. European Union authorities haven't approved the planting or importation of any new genetically engineered crop since 1998. Despite widespread hunger, Zambia recently turned away U.S. food aid because the shipments contained genetically engineered corn. And for the last four years Mexico has not allowed CIMMYT to test genetically engineered corn outside a greenhouse. Indeed, if opponents of genetic engineering have their way, no genetically engineered corn will ever grow in Mexican soil.

Mexico is the ancestral homeland of corn, the place where ancient peoples first domesticated this crop. It is also the world's singular storehouse of corn's genetic diversity: Mexican farmers maintain an astonishing number of corn varieties. Adapted to an enormous array of climates, Mexico's corn comes with kernels in black, white, and every color in between.

So when scientists reported finding traces of genetically engineered corn in remote corn fields of southern Mexico a year and a half ago, it was particularly troubling to those worried about the genetic diversity of this unique resource. Indeed, although the study's findings have been hotly contested by other researchers, some environmentalists believe it uncovered a disaster of epochal proportions. "The Mesoamerican centre of agricultural biodiversity is contaminated with GM [genetically modified] maize," announced the ETC Group, an activist organization based in Winnipeg, Canada. Greenpeace declared that "this irresponsible contamination…is putting at risk the whole genetic structure of the corn populations."

The image of engineered plants poisoning a biological well is powerful but misleading, says Mauricio Bellon, a

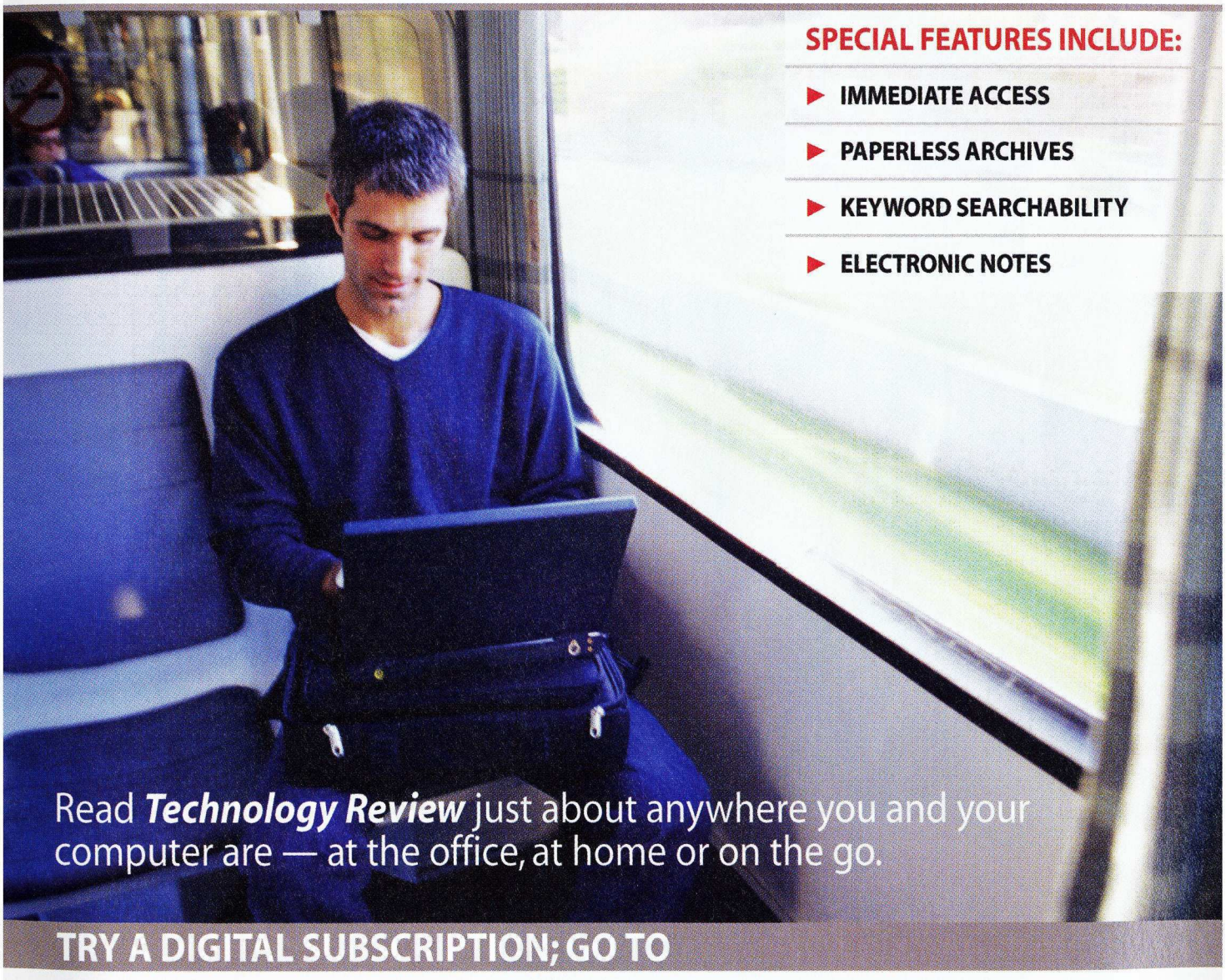
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CIMMYT human ecologist who has been studying Mexican farmers' maintenance of their traditional varieties, or landraces: "People think that landraces are like fragile vases in a museum, but that's not the case." Landraces aren't pure, and they aren't static, says Bellon. Mexican farmers, he discovered, continually bring in new seed from neighbors and even from faraway villages to add to and, they hope, invigorate their fields. It's a bit like shuffling in cards from a new deck to increase the odds of a winning hand. The good cards—the superior genetic traits—stand a chance of staying in the game. Farmers try to choose them for replanting the following year, and they discard the bad cards.

There's no apparent reason why genetically engineered crops should displace or destroy Mexico's genetic diversity, Bellon says. The new genes would become part of the mix, and they'd persist only if farmers liked the results. But, he hastens to add, genetically engineered corn in Mexico may pose other risks that need careful consideration.

Indeed, nearly everyone who has explored the surge of opposition to genetically engineered crops—in Mexico and elsewhere—has discovered a mélange of motivations. Concerns about the integrity of nature and the safety of food are mixed with hostility for the corporations that have been driving this technology into the marketplace. Mexico imposed a moratorium on the planting of all genetically engineered corn, for instance, not when CIMMYT conducted its first field trials, but when St. Louis-based Monsanto and other companies began lobbying for approval to sell their genetically engineered crops to Mexican farmers.

One encounters antipathy toward biotechnology, in fact, within CIMMYT as well. CIMMYT's crusty plant breeders sometimes dismiss their organization's biotech program as a boondoggle, an expensive fad that has squandered millions of dollars without delivering, so far, a single useful product to farmers. Many resent the deals—accompanied by confidentiality clauses and agreements to protect intellectual property—CIMMYT's biotechnologists have struck with companies. The center should be accountable only to the world's poorest farmers, these critics say, not multinational biotechnology empires. At this point—where the humanitarian mission of CIMMYT encounters the goals of private enterprise—the tale of apomixis takes its final ironic twist. For according to some observers, the corporate friends of apomixis are also its worst enemies.

THE REASON IS SIMPLE: SEED companies have a financial incentive to keep self-cloning corn out of farmers' hands because apomixis breaks a natural sort of copy protection. Seed companies sell mostly hybrids not just because they yield more but also because the differences between hybrid corn and its offspring are more pronounced than in inbred lines. Those differences drive farmers back to the dealer each year for fresh supplies of seed. Apomictic hybrids, on the other hand, could reproduce themselves exactly—and that would be bad for business.

No surprise, then, that many observers believe the firms sponsoring CIMMYT's research want to use apomixis mainly as an in-house tool for speeding the complicated process of breeding hybrids and producing seed. Before selling seed to farmers, the companies could disable the self-cloning ability. "The thinking in the seed business is that apomixis would be more useful if you could turn it off," says Anthony Cavalieri, vice president of trait and technology development at Pioneer Hi-Bred. Ultimately, CIMMYT's corporate sponsors might see topnotch apomictic hybrids from CIMMYT as competition. "If the for-profit sector controls apomixis as a tool, it's not going to want it used by the public sector to make self-replicating hybrids," says Gary Toenniessen, who manages the Rockefeller Foundation's programs in global agriculture. And any company that holds patents on an essential piece of apomixis technology would be able to block its use, at least until the patent expired.

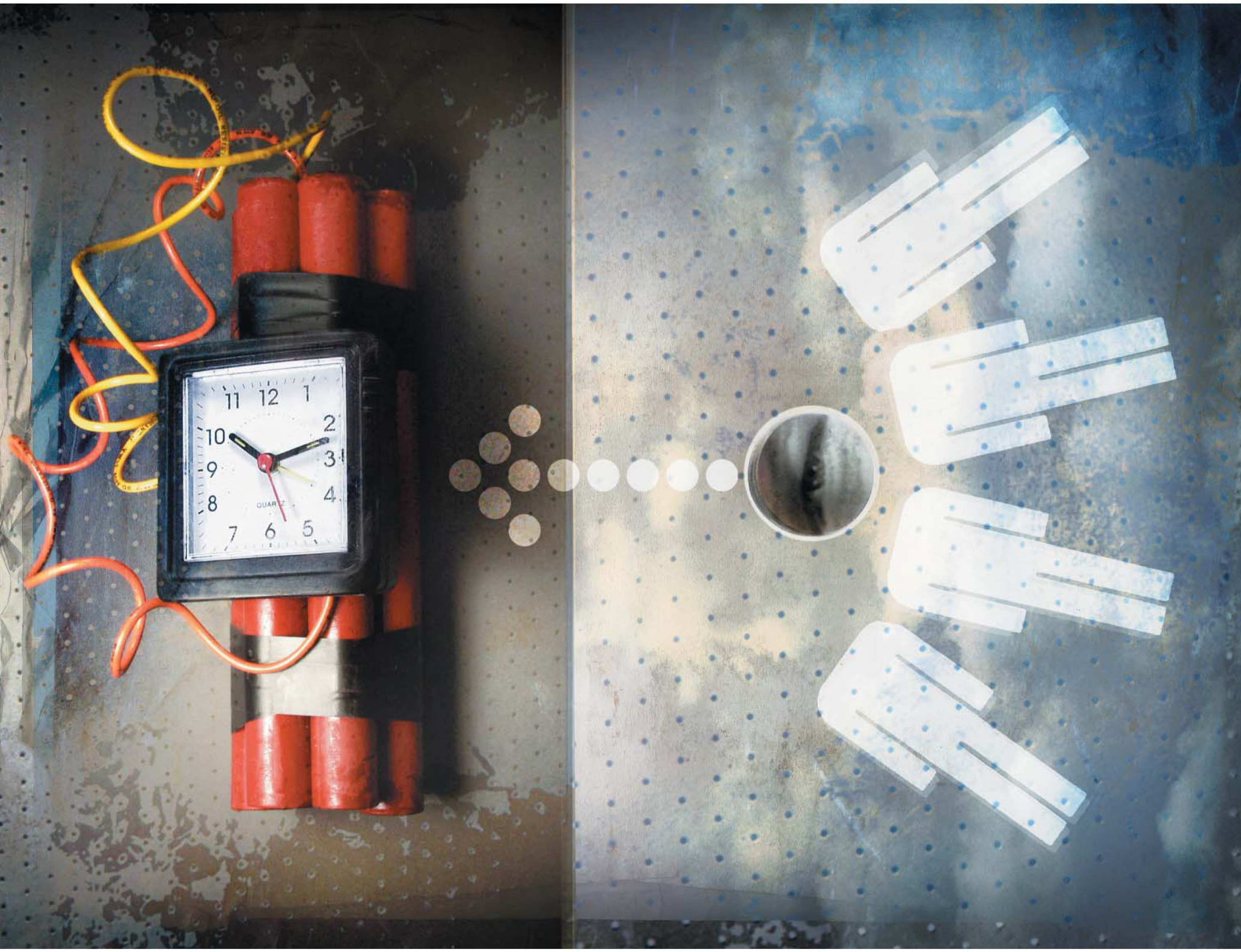
In 1998 Jefferson of Australia's Center for the Application of Molecular Biology to International Agriculture helped persuade more than 20 leading apomixis researchers from around the world to declare their opposition to corporate control of the research. The so-called Apomixis Declaration stated, "We are deeply concerned…that the current trend towards consolidation of plant biotechnology ownership in a few hands may severely restrict access to affordable apomixis technology." Unfortunately, says Jefferson, "scientists are sluttish beyond words." Many apomixis researchers have since signed up with private companies.

CIMMYT's scientists insist there's no problem. They maintain that their corporate sponsors have agreed to allow the center to distribute apomictic corn to poor farmers in developing nations. "It's perfectly clear," says Olivier Leblanc. "For CIMMYT clients, there is complete freedom." But even Yves Savidan, the architect of CIMMYT's apomixis collaboration with industry, has grown skeptical. "If you're not in control of everything, you're not in control of anything," he says.

Even before the first apomictic self-cloning corn seeds are ready to be sown, the prospect looms that political debates and corporate interests will poison the ground. And that would be a blight not only on the future of poor farmers, but also on the reputation of agricultural biotechnology—a field already dogged by accusations that its science has not done enough for the human good.

Producing biotech crops that feed the poor and improve the lives of farmers in the developing world would convincingly refute such accusations. David Hoisington, director of CIMMYT's biotechnology program, believes that such crops are on their way. CIMMYT's first genetically engineered corn, a nonapomictic variety that repels the stem borer worm, is ready for field tests. In another decade or so, plots of apomictic corn could mark a new entry in the CIMMYT Walk of Fame. "The technology is such a powerful tool for solving problems," says Hoisington, "that it has to be accepted." TR

If the for-profit sector controls apomixis as a tool, it's not going to want it used by the public sector to make self-replicating hybrids. And any company that holds patents on an essential piece of the technology would be able to block its use.


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NEW INTELLIGENCE SOFTWARE HELPS INVESTIGATORS SEE PATTERNS AND WRING MEANING FROM A CHAOS OF CLUES—HELPING TO FIND TERRORISTS BEFORE ATTACKS TAKE PLACE.

by m. mitchell waldrop

illustrations by stuart bradford

can sense-making keep us safe?

A few years ago,

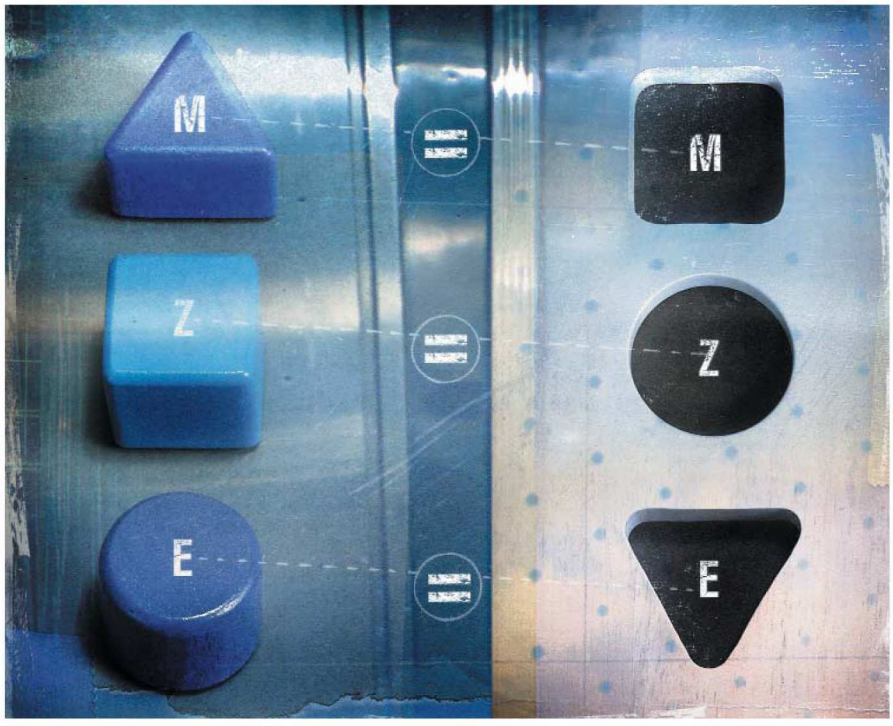
says Jeff Jonas, a friend arranged for him to give a talk at the secretive National Security Agency, widely renowned as the most technology-savvy spy shop in the world. He wasn't quite sure what to expect. "I had never even set foot in Washington," says Jonas, founder and chief scientist of Systems Research and Development, a Las Vegas maker of custom software that was being used by casinos and other companies to screen employees and prevent theft. True, Jonas was proud of NORA, his company's Non-Obvious Relationships Awareness analytic software. The system can cross-correlate millions of transactions per day, extracting such items of interest as the info nugget that a particular applicant for a casino job has a sister who shares a telephone number with a known underworld figure. But Jonas reckoned that this would seem like routine stuff to the wizards of the NSA.

Wrong. "I was shocked," Jonas says. After his talk, several members of the audience told him that his technology was more sophisticated than anything the NSA had. And now Systems Research and Development has several government customers. Indeed, he says, "since September 11, the urgency has really peaked."

But maybe Jonas shouldn't have been shocked. There are many explanations for the failure of the U.S. Central Intelligence Agency, the Federal Bureau of Investigation, and their fellow intelligence agencies to "connect the dots" in time to stop the terrorist attacks. The list of reasons could start with the well-known inability of these organizations to communicate. But their analysts' out-of-date tool kit surely didn't help. Over the past decade, the business market has seen extraordinary advances in data mining, information visualization, and many other tools for "sensemaking," a broad-brush term that covers all the ways people bring meaning to the huge volumes of data that flood the modern world. And yet, in a major study released last October, the Markle Foundation's Task Force on National Security in the Information Age emphasized that "we have not yet begun to mobilize our society's strengths in information, intelligence, and technology."

That's not quite fair. The mobilization has begun, albeit in piecemeal, internecine fashion. Individual agencies have been eager customers for the new technologies for several years. And since 1999 the CIA has been funding some of the most promising sensemaking companies (including Jonas's) through In-Q-Tel—the agency's own Arlington, VA-based venture capital firm. What's more, in early 2002 the U.S. Defense Advanced Research Projects Agency upped the ante by systematically developing sensemaking technology through its controversial new Information Awareness Office. But the problem, says the Markle task force, is that because each of the agencies is so intent on obtaining its own intelligence and buying its own technology, there has been no overall planning or coordination. Nor has a significant fraction of the annual $38 billion budgeted for homeland defense been devoted to building a capacity for sharing information or integrating its analysis.

That won't do. The era inaugurated with such fury by the assault of September 11 imposes a technological imperative: put the pieces of the data gathering and analysis machinery together. We must mobilize the nation's strengths in networking and analytical technology to create what the Markle task force calls a virtual analytic community: a 21st-century intelligence apparatus that would encompass not just the agencies in Washington, but also private-sector experts, local officials, and even ordinary citizens. The cold war was a mainframe-versus-mainframe confrontation, but the war against terrorism pits the United States against a network. It's time to take intelligence gathering and interpretation into the network age.



collecting the dots

"We're entering a new era of knowledge management," declares In-Q-Tel CEO Gilman Louie. "Call it the era of chaos or complexity or whatever trendy term you want. We're looking at a level of integration that has never been contemplated before in government."

It's too soon to know how (or whether) officials in Washington will approach this challenge. Any effort will most likely be spearheaded by the U.S. Department of Homeland Security, which is still in the process of organizing itself. Nevertheless, it certainly is not too soon to take a look at how such a virtual intelligence system might work and how it might use technology most effectively.

Before we can connect the dots, we first have to *collect* the dots. And in the war on terrorism, notes the Markle report, "most of the people, information, and action will be in the field." Critical clues can come from unexpected places: "a cop hearing a complaint from a landlord, an airport official who hears about a plane some pilot trainee left on a runway, an FBI agent puzzled by an odd flight-

school student in Arizona, or an emergency room resident trying to treat patients stricken by an unusual illness."

Likewise, in most cases, most of the expertise required to interpret particular pieces of intelligence or to devise responses will reside with local officials and other agencies outside the centralized-intelligence community. If, for example, a town is facing a threat to its water system, an appropriate response team might include state officials and local hospitals, as well as public utility commissioners, building inspectors, and watershed conservationists. So the virtual community's most basic requirement will be an online meeting space that's open to any and all such officials. Such a system could be implemented as a virtual private network running on top of the Internet, with standard encryption techniques providing the security. Many companies have been operating virtual private networks for several years.

But simple communication is only part of what's needed. Investigators from myriad federal, state, and local agencies will also have to share data quite freely, if only because there's no way to know in advance what information will be relevant to whom. This commonsensical notion is *not* the norm in conventional intelligence agencies, where to protect sources and methods, information is kept tightly compartmentalized. Yet information sharing among employees is increasingly common in the corporate world; open communication helps companies become much more flexible, innovative, and responsive to customers. And it is even taking root in the Pentagon, where information sharing is known as network centric warfare. A prime example: the Afghanistan war, during which everyone involved—imagery analysts, fighter pilots, and experts on Afghanistan itself—had access to the same data and could interact in real time.

a time to share

It's one thing to advocate widespread data sharing; achieving it is another. Even with access to a secure network, for example, local police officials and other municipal officials may not have enough storage capacity or processing power to make good use of the data. But maybe such investigators could tap into the network itself for the resources they need. During the past few years, researchers have made rapid progress in "distributed computing," which uses high-speed Internet connections to link many computers so they work together as one machine. Grid computing, for instance, links mainframes together, and peer-to-peer systems similarly unite personal computers. But for all users, even if their own computers are terribly underpowered, the bottom line is much the same: so long as they can plug into the network, they will be able to access data files, analytical tools, and raw computational power as easily as if they were sitting at the world's greatest supercomputer. In a sense, they will be.

Provision of ample processing power will not completely alleviate the problems of information sharing, however. First, there's a technical issue: old databases (and even many new ones) store information in myriad incompatible formats. Then there's a policy issue: a long list of organizations control critical databases, and the overseers of many of them believe that their files contain information too sensitive to release to outsiders.

The trick is to share the information anyway. Techniques to make this feasible are under development. Innovation is especially active on systems for "structured" data: the kind in which names and numbers fit neatly in rows and columns, as in a spreadsheet or airline reservations database. One approach, advocated most notably by database giant Oracle, is to convert everything into a standard format and store it all in a common data warehouse. This approach has the virtue of simplicity, and because it allows for efficient searching, it is widely used for commercial data mining—the systematic processing of data to find useful pieces of information. Indeed, it is the approach Systems Research and Development uses for its system, which can monitor thousands of data sources in real time.

"Our largest installation to date was for a large corporation that wanted to aggregate data on customers and has 4,200 daily feeds," Jonas says. That's about nine million transactions per day. As each transaction occurs, the data it generates are translated into a standard format—typically one based on extensible markup language, an information-rich variant of the hypertext markup language used to code most Web pages. The proprietary software further refines the data using a process that tries to determine whether records for, say, "Bob Smith," "Rob Smith," and "Robert Smith" represent three people, two, or one. "Often the differences are unintentional," says Jonas. "But sometimes it's people trying to obfuscate who they are." Finally, he says, the algorithm looks for correlations that might relate one person to someone on a terrorist watch list. Results are generated in about three seconds. "Imagine that you have this ocean of data," he says. "When each new drop comes in, we can see all the ripples."

For one client, a large U.S. retailer facing nearly $40 million per year in fraud-

A Sampling of Sensemakers

COMPANY	LOCATION	ACTIVITY
Entrieva	Reston, VA	Management of unstructured data such as text files, Web pages, and audio and video
i2	Cambridge, England	Information visualization software
IBM	Armonk, NY	"Federated" management of structured data such as an airline reservations database, as well as unstructured data
In-Q-Tel	Arlington, VA	CIA's venture fund for companies with technologies that show promise for intelligence work
Intelliseek	Cincinnati, OH	Integration of information search and analysis tools
Stratify	Mountain View, CA	Management of unstructured data
Systems Research and Development	Las Vegas, NV	Software that finds subtle patterns in complex webs of relationships and transactions

related losses, Jonas's software examined the records of the company's thousands of employees and identified 564 who had relationships with either a company vendor—a possible source of illegal collusion—or a person the retailer previously had had arrested. And in a trial conducted for a retail association in Washington, the system turned up evidence of a ring of underage thieves who had been shoplifting a popular brand of jeans.

The company now has installations running at the FBI and several other government agencies, Jonas says. Most of that deployment is new since September 11. But if one of these had been monitoring the appropriate data feeds in late August 2001, he says, it might have noticed that using their real names and addresses, two men on the terrorist watch list of the U.S. Department of State had purchased airline tickets for American Airlines flight 77, which hijackers would crash into the Pentagon. Noting that coincidence, the system might have checked to see whether anyone else was using the addresses, frequent-flier information, and phone numbers provided by the two men.

Continuing in this way, the system might have created a chain of associations leading to many of the other 19 hijackers, including ringleader Mohammad Atta. Without the advantage of hindsight, of course, such a chain would not necessarily have screamed, Terrorists! But it might have put analysts on alert. And, with several days remaining before the scheduled flight, they might have turned up other links to such puzzling information not available online as a common interest in flight schools. Maybe—just maybe—agents might have stopped the conspirators at the gate on the morning of September 11.

database babel

We can never know what might have been. In the meantime, however, we must still contend with the problem of very sensitive data. The owners of certain data don't want to let their information anywhere near a common data warehouse. In such cases, the notion of "federated" information suggests an approach that may be more applicable.

"It's a way to have integration without centralization," explains Nelson Mattos, director of information integration at IBM, which is forcefully developing this approach. The idea is to leave each data repository where it is—forget the warehouse—and instead provide it with a "wrapper": a piece of software that knows how to translate the inner workings of that particular database to and from a standardized query language. This way, says Mattos, "a single query can be sent out to access all forms of information, wherever it's stored." The answers that come back are arrayed on the user's screen in neat rows and columns, as if, he explains, they had been "all stored in a single database."

SEPTEMBER 11 BROUGHT A TECHNOLOGICAL IMPERATIVE: PUT THE PIECES OF DATA GATHERING AND ANALYSIS MACHINERY TOGETHER.

This architecture solves the compatibility problem automatically, Mattos says. It also helps to ensure that sensitive information goes only to the right people. In a federated system, he says, "I continue to own my data. But I can write a wrapper that allows outsiders to access parts of my data, without giving away the whole thing." The wrapper around a medical database might answer queries from public health officials about statistical information while denying access to information about specific patients. Likewise, the wrapper around an intelligence database might protect sources and methods. Such a system might be augmented by digital rights management, which could make it impossible to copy a digitally shared document.

start making sense

As powerful as they are, such tools as data mining help only to collect and refine the dots. Federated systems, for their part, help only to share these clues. And neither approach helps connect the dots—or piece together an understanding of what a cadre of terrorists or another criminal group is up to. This is perhaps the most difficult aspect of sensemaking. Working from fragmentary clues to develop an understanding of the how and why of a crime is what detectives do. It's also what scientists do, as they consider experimental evidence and develop a hypothesis that explains a phenomenon. In many ways, sensemaking is an essentially human process—one that's not going to be automated anytime soon, if ever. "You need good human judgment," emphasizes In-Q-Tel's Louie, "and an ability to draw sensible conclusions," qualities that must be built on knowledge of history, religion, culture, and current events.

Still, technology can help. For example, consider how many clues (and indeed, how many of the insights needed to make sense of them) have their origins not in structured information, but in the vast realm of so-called unstructured data, which range from text files and e-mail to CNN feeds and Web pages. And "vast" is the word for it; when fully digitized, CNN's video archives alone will require some four *petabytes* of storage, according to IBM, which is performing the conversion. That's the equivalent of about a million PC disk drives. No human being can hope to read, view, or listen to more than the tiniest fraction of the world's unstructured information. Even the best search engines are blunt tools. Do a Google search on "bonds," for instance: you'll get about five million hits on pages related to municipal bonds, chemical bonds, Barry Bonds, and a slew of other concepts.

What you really want is to have only the documents that interest you automatically find their way to you, says Ramana Venkata, founder and chief technical officer of Stratify, a Mountain View, CA, company funded by In-Q-Tel. Ideally, the documents would do more than just announce their existence. "They should put themselves into the context of other documents or of key historical trends," Venkata asserts. And, of course, they should prioritize themselves, identifying which are most important, so that you don't drown in information. For now, that's still a pipe dream. But in the past few years, Stratify and a number of other companies have taken steps in that direction with their development of information classification software.

Even before September 11, Stratify's Discovery System had been in use by the

CIA and other intelligence agencies, Venkata says. To understand how it works, he suggests, imagine that somebody hands you a 30-gigabyte disk drive that is discovered in a cave in Afghanistan and asks you to figure out what's on it. Or maybe you've downloaded a big collection of documents from a Web search. However you get them, he says, "the idea is to understand and organize the documents in terms of the topics and ideas they refer to, not just the specific words they contain."

The first step, says Venkata, is to develop a taxonomy for the collection—a kind of card catalog that assigns each document to one or more categories. A taxonomy for information about aircraft, for example, might have subcategories for "helicopters" and "fixed wing," with the latter subdivided into "fighters," "bombers," "transports," and so on. Stratify's software is set up to use or modify a standard taxonomy, says Venkata. Some organizations already have them. (Over the years, librarians have developed elaborate schemes for classifying information about biology, engineering, and countless other fields.)

But the software also can generate taxonomies automatically. Using proprietary algorithms, it scans through all the documents to extract their underlying concepts. On the basis of their conceptual similarity, it groups the documents into clusters, then links these clusters into larger clusters defined by broader concepts, continuing until every cluster is linked into a single taxonomy.

Furthermore, notes Venkata, the system assigns each document (and every new document that is added) to its appropriate place within the taxonomy. To ensure accuracy, Stratify's software pools the results of multiple sorting procedures and algorithms, which range from manual sorting and supervised machine learning ("*This* document is a good example of *that* category; look for others like it") to matching the statistical distribution of words. When appropriate, the system assigns documents to more than one category.

Of course, the user can edit the machine's results at any time. But the machine-generated taxonomy provides an efficient and effective way to understand what a collection of documents is *about*. After all, Venkata says, "taxonomies are not an end to themselves. They're tools to help you deal with huge amounts of information in a much more intuitive, natural way—to see patterns when you don't know what you're looking for."

seeing is believing

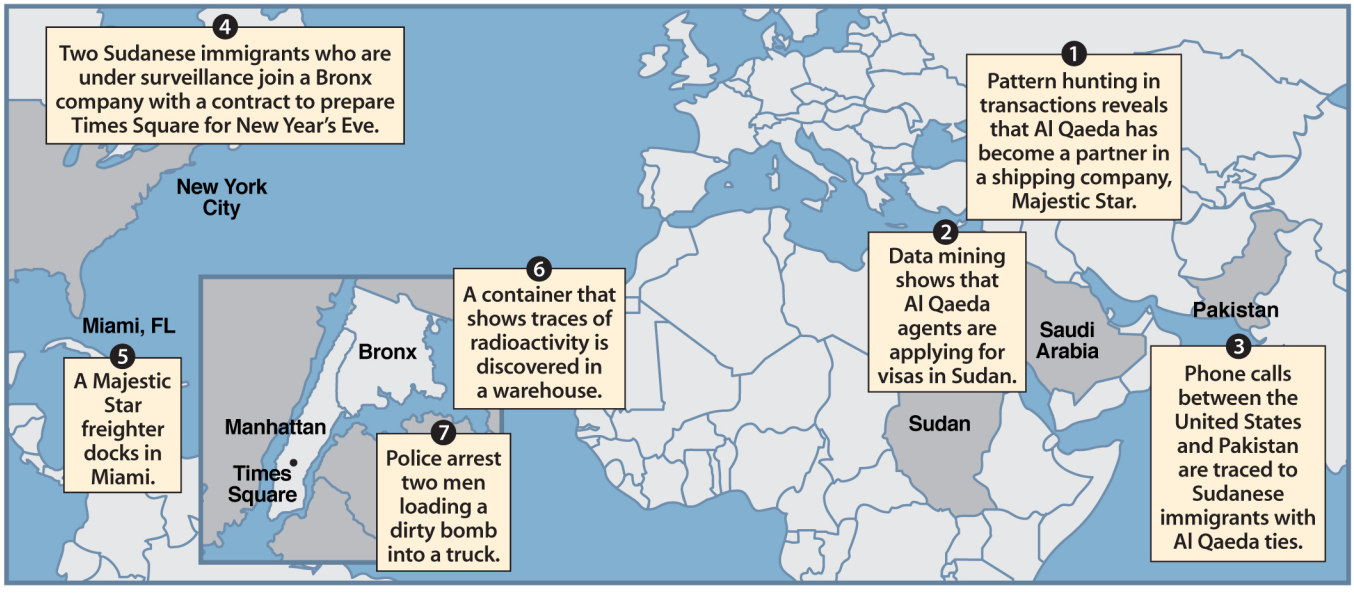
Once a system or framework is in place, other technologies can help keep track of the multitude of clues, not to mention the enormous array of possible interpretations. A good example is Analyst's Notebook, a set of visualization tools developed over the past decade by a Cambridge, England-based company called i2. Originally created for police and insurance investigators, Analyst's Notebook has recently attracted a following among U.S. intelligence agencies. Indeed, the company claims that President Bush is regularly briefed with charts from i2.

Right after September 11, says Todd Drake, i2's U.S. sales manager, "we were asked to come help out at FBI headquarters," where a hurriedly convened interagency intelligence group was struggling to get up and running. "Our software was already heavily deployed inside both the FBI and the Defense Intelligence Agency. So we saw cases where a DIA guy would walk past the cube where an FBI guy was sitting and say, 'Hey, I know this program!' And suddenly they'd be working together. If the bureaucratic barriers fall, technology can help cooperation happen."

Analyst's Notebook provides timelines that illustrate related events unfolding over days, weeks, or even years, as well as transaction analysis charts that reveal patterns in, say, the flow of cash among bank accounts. But most dramatic of all are its link analysis charts. These look a bit like the route maps published in airline magazines, with crisscrossing lines connecting cities around the world. But the "cities" in these charts are symbols that represent people, organizations, bank

Cracking a Case

A dirty bomb is set to go off in Times Square on New Year's Eve. Plotters leave clues scattered around the world.



JOHN MACNEILL

accounts, and other points of interaction. (An i2 demonstration chart that traces only publicly available information shows the links that tie the September 11 hijackers to Osama bin Laden.)

Each element in a chart is hyperlinked to the evidence that supports it; that evidence, in turn, is tagged with such additional information as sources, estimated reliability, and security levels. If it later becomes apparent that information from a particular source is in fact *dis*information—that is, lies—a single keystroke can purge from the chart all of that source's contributions. It is similarly straightforward to eliminate elements that are related to classified information. The "sanitized" chart, still quite useful, may be freely shared with collaborators who lack the requisite security clearances. "Why," Drake asks, "should the Drug Enforcement Administration have to redo something the Defense Intelligence Agency already did?"

DERIVING MEANING FROM FRAGMENTARY CLUES IS AN ESSENTIALLY HUMAN PROCESS. BUT TECHNOLOGY CAN HELP.

thinking straight

Yet another way technology can enhance sensemaking is by providing tools that help steer analysts clear of certain mental pitfalls. That's the goal of the Structured Evidential Argumentation System, which was developed by SRI International under Project Genoa, a recently completed DARPA program. (Genoa II, a follow-on project, is now under way at DARPA's Information Awareness Office.) According to SRI team leader John Lowrance, the argumentation system "helps you organize your thinking and keeps you from jumping to conclusions too soon." Too often, he says, when people are struggling to make sense of fragmentary clues, they succumb to the subconscious temptation to focus on one likely interpretation, neglecting to give other possibilities the attention they merit.

To help analysts avoid such blinkered thinking, SRI's system uses "structured argumentation," which marshals evidence according to a specified template. Depending on the task at hand, Lowrance says, the template might take the form of a flow chart, say, or a legal argument. The tool Lowrance's team developed appears as a hierarchy of yes-or-no questions. Someone monitoring country X might start an analysis with a high-level question: Is country X headed for a political crisis? Answering that question requires the analyst to get answers to several more specific queries, such as, Is political instability increasing? Is there a government power struggle with potentially destabilizing consequences? Each of those questions, in turn, might find its answers in terms of still more specific queries: Is there evidence of growing factionalism?

This drilling-down process continues until it generates questions that can be answered with specific pieces of intelligence, such as field reports, Internet downloads, or the output of data-mining systems. On the basis of those results, the analyst refers to a five-color scale and selects the color that conveys the degree of the answer's certainty: red, for "almost certainly yes"; orange, for "likely"; and so on, down to green, meaning "almost certainly no." The system automatically aggregates these conclusions into color-coded assessments of the higher-level questions. And it provides a number of displays—including a color-coded overview of the entire hierarchy—that starkly outline the areas of greatest concern in red and orange.

SRI's tool gives "a very quick sense of what's driving the conclusion," says Lowrance. Perhaps its most important benefit, he says, is that because the tool communicates results specifically, rapidly, and graphically to people who are not familiar with a situation, it offers an effective alternative to writing memos. SRI is exploring the possibility of developing a commercial version.

open secrets

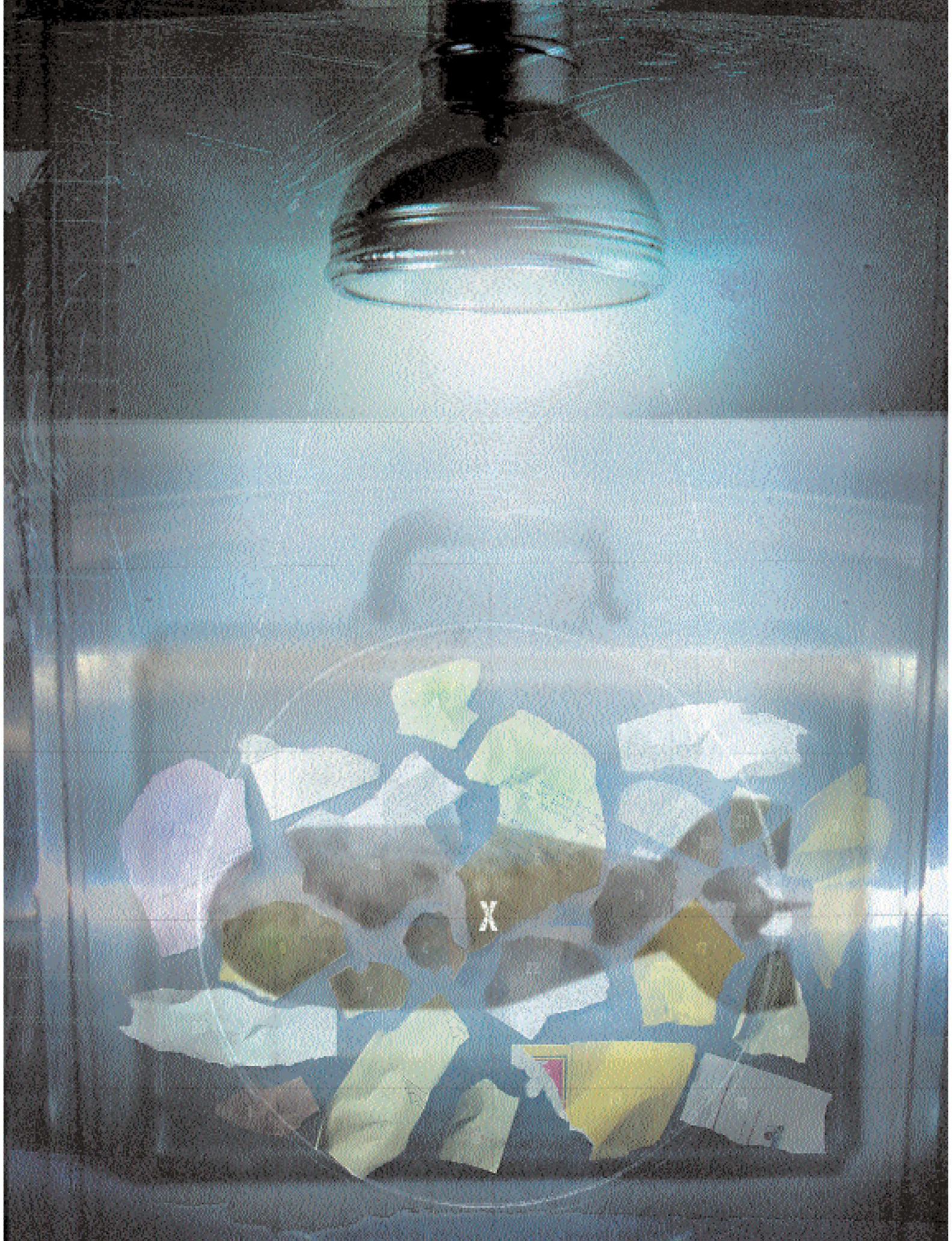
Software companies have come up with a host of other analytical tools. In fact, with so many already available or under development, analysts are challenged to get everything to work together seamlessly. That's why In-Q-Tel is funding Cincinnati-based Intelliseek, one of the few companies that specialize in such integration.

"There is no silver bullet," says Intelliseek CEO Mahendra Vora. "And no one company has the complete solution to solve all our homeland security problems." What's needed, Vora says, is an open architecture that can incorporate new applications as they come along. For this reason, the company's systems use open standards, such as extensible markup language, that make it easy for different pieces of sensemaking software to work in harmony. This open technical approach is, perhaps, a metaphor for the new age of homeland security itself.

For many people, mere technical protections against governmental infringement on privacy provide little reassurance. Witness last fall's uproar in response to the news that John Poindexter, notorious for his involvement in the Iran-Contra affair, would head DARPA'S Information Awareness Office. (William Safire fulminated in the *New York Times* about "this master of deceit" and his "20-year dream" to snoop on every U.S. resident.) Many Americans have a visceral aversion to domestic-intelligence gathering in any form, notes Lee Tien, an attorney with the Electronic Frontier Foundation, and, he adds, they have good reason. Whenever he hears a bright new idea for high tech intelligence, he says, "My question is, 'What would J. Edgar Hoover do with such a system?'"

If anything can improve the level of trust, says Tien, it is even greater openness. "Skepticism grows from secrecy," he says. "If officials are going to hide, not give any details, and just tell us they're protecting privacy, that's not a strategy that will reassure people." Conversely, he says, by being as forthcoming as possible, the Department of Homeland Security and any other agency that coordinates the intelligence-gathering effort could reap big dividends in the form of public cooperation and political support.

We can only savor the irony. It is our openness as a society that makes us so vulnerable to terrorism. Yet our openness—on both the technological and the human levels—may very well be our strongest defense. TR


X

World's biggest battery: Two 10-meter tall electrolyte tanks in Columbus, MS, will help steady the region's power supply by storing electricity from the grid. An orange pipe vents fumes during construction.

RECHARGING THE POWER GRID

Huge batteries could provide an upgrade to the nation's floundering power grid, providing cleaner and more reliable electricity while sidestepping the need for new power plants and transmission lines.

BY PETER FAIRLEY

PHOTOGRAPHS BY GRAHAM MACINDOE

Fighter jets scream over Columbus Air Force Base, a sprawling military facility in eastern Mississippi that is especially busy these days training aviators for the war on terror. But for all the high tech aeronautics on display overhead, the bustling Air Force base often relies on an old-fashioned diesel generator to keep radar and communications humming and the jets from colliding. That's because the region's antiquated, overloaded power grid dishes out 25 blackouts a year, as well as another hundred or so voltage fluctuations that crash sophisticated flight simulators.

The solution—the world's largest battery—is under construction nearby. Two cavernous steel tanks, each one 10 meters tall and 20 meters in diameter, will soon hold nearly four million liters of concentrated salt solutions, electrolytes that will be charged and discharged by 24,000 fuel cells in an adjacent building. At night this installation, known as a flow cell battery, will suck electricity from the grid and store the energy, which it will discharge during the day when power lines are strained. When blackouts strike—common in this tornado-prone region—the huge battery will keep the base humming for up to 24 hours.

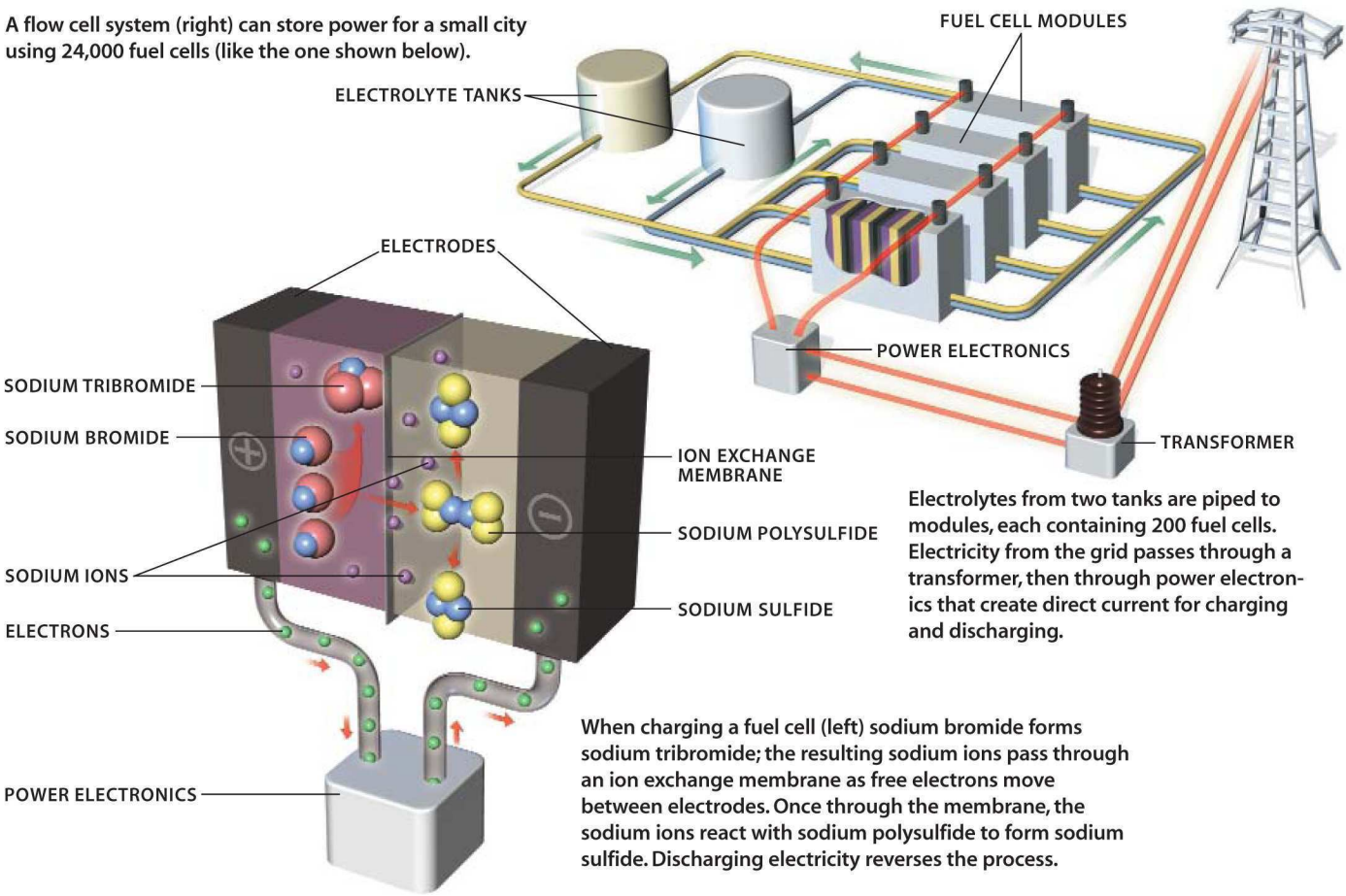
This massive battery represents more than a backup power supply for an isolated military facility. It's a bold experiment in large-scale electricity storage on the power grid—the aging maze of interconnected power plants and transmission lines that cover the country. Today's grid operates with minimal storage, so at all times, electricity flows must exactly balance the power that's being consumed. Partial solutions are available in a new class of digital switches that more efficiently deliver electricity during crunch periods *(see "Power Gridlock," TR, July/August 2001)*. But devices such as the Columbus flow cell, which is being built by the federally operated Tennessee Valley Authority and Swindon, England-based Regenesys Technologies, go one step further. By storing hours of electricity, flow cells offer, for the first time, the possibility of freeing the grid from the need to continuously balance production and consumption.

The implications of a newly flexible grid are immense. Sufficient storage capacity would relieve pressure to build new power plants and transmission lines, prevent regional blackouts, even speed the adoption of wind farms and solar panels by transforming intermittently produced power into steady reserves. Also, by dampening glitches and power spikes, the more flexible grid would provide the high-quality power needed for today's sensitive electronic equipment. Problems ranging from blackouts to the voltage fluctuations that cause chaos in high tech manufacturing sap an estimated $119 billion from the U.S. economy every year, says Kurt Yeager, CEO of the Electric Power Research Institute, a utility-funded R&D consortium in Palo Alto, CA. This hemorrhage is just one indicator that power grid fundamentals need rethinking, he adds. "The world as we know it can't continue. Prudent people would not wait for the lights to go out to do something about it. We've got to change the architecture of the grid," he says.

The storage solution is coming, albeit slowly. About a dozen companies worldwide are developing and testing technologies capable of storing large amounts of electricity on the grid *(see "Battery Power for the Grid," p. 56)*. Over the past decade, for

Anatomy of a Flow Cell Battery

A flow cell system (right) can store power for a small city using 24,000 fuel cells (like the one shown below).



Electrolytes from two tanks are piped to modules, each containing 200 fuel cells. Electricity from the grid passes through a transformer, then through power electronics that create direct current for charging and discharging.

When charging a fuel cell (left) sodium bromide forms sodium tribromide; the resulting sodium ions pass through an ion exchange membrane as free electrons move between electrodes. Once through the membrane, the sodium ions react with sodium polysulfide to form sodium sulfide. Discharging electricity reverses the process.

SLIM FILMS

example, advanced battery systems have been demonstrated by Tokyo-based NGK Insulators at more than 30 sites in Japan. A smaller version of flow cell technology developed at the University of New South Wales in Australia and distributed by VRB Power Systems of Vancouver, Canada, will soon support power flows to a remote but growing community in southern Utah. And electricity distributors in California, Hawaii, and Denmark are eyeing Regenesys's flow cell technology as a way to ease congestion and prepare their transmission networks for rapidly expanding flows of renewable energy. "Storage distributed around the grid would make the whole system more robust and more efficient," says Ali Nourai, a technology consultant at American Electric Power in Columbus, OH, one of the largest electric utilities in the United States. "The need is there, the market is there, and the price is coming down," he says. "In two to five years, storage will be all over the place."

POWER PLAY

The idea of storing large amounts of electricity is, of course, not new. Indeed, the first large-scale storage systems were installed in Italy and Switzerland in the 1890s. These systems turned hydroelectric power stations into giant batteries. Pumps forced water uphill into reservoirs; later, gates opened, releasing the water to spin turbines and produce electricity. Today, hydroelectric storage facilities around the world provide about 90 gigawatts of electricity, a figure that translates into about 3 percent of global electricity capacity. But because not every location has mountain lakes—and few communities are eager to submerge thousands of acres to create a giant battery— it's been nearly two decades since the United States has added a pumped hydro station.

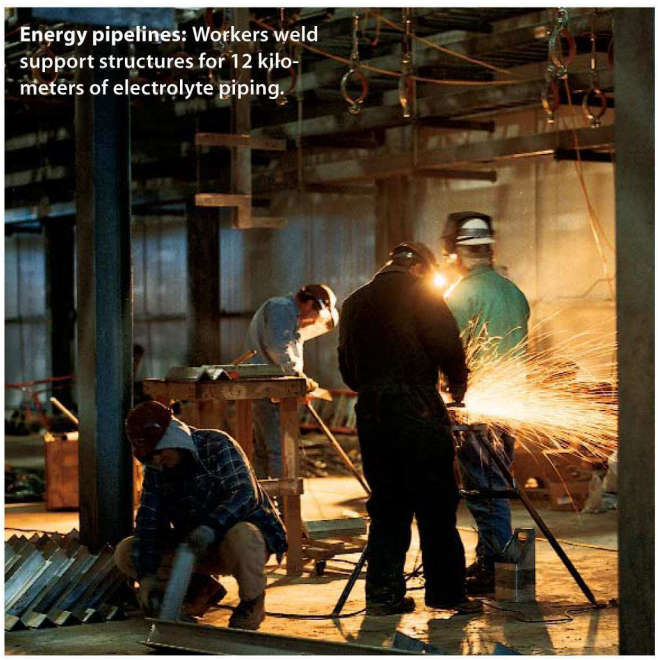
Yet electricity storage is needed more than ever. Power companies are obliged to build supplemental electricity-generating plants, nearly all of which burn fossil fuels, to meet demand during the busiest hours of the day. Just turning those plants on and off emits blasts of pollution. It's an expensive and wasteful way to generate power, says Nourai. "In your electricity bill, there's a demand charge, which you have to pay whether you used the electricity or not. Why? Because a big generator has been purchased for the day that you need that power." What's more, the dearth of storage means more transmission lines are needed to respond to peak power demands, a job strategically placed giant batteries could perform with greater efficiency.

The reality is that those transmission lines aren't being built. They're about as popular as a hydroelectric storage lake, and they are uglier. As a result, the stressed-out transmission network is not always able to provide the steady supply of electricity required to run sophisticated electronic equipment. A single fallen tree limb can send shock waves down overloaded lines, causing nervous breakdowns in the communications servers, hospital equipment, home computers, and other digital devices that account for about 10 percent of U.S. power consumption.

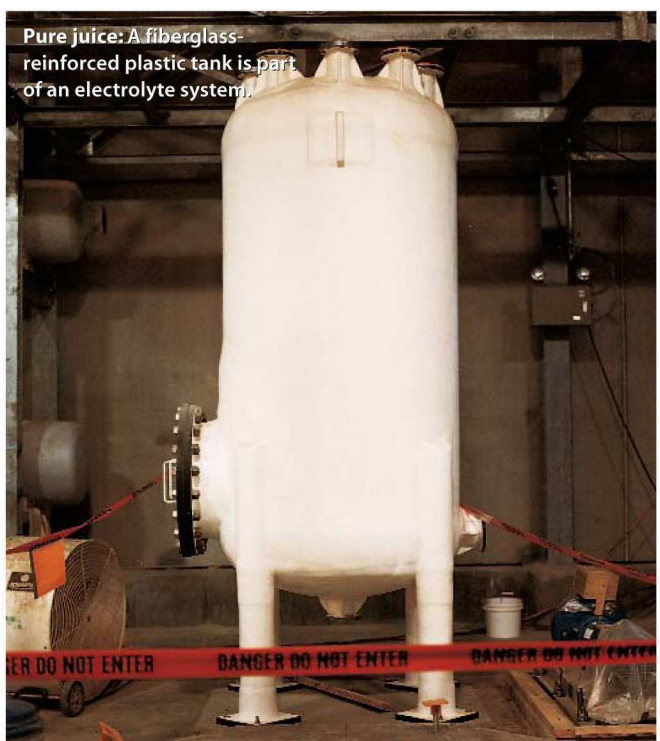
Indeed, gridlocked power lines contributed to the crisis that nearly bankrupted California two summers ago, when energy traders were exploiting supply constraints and manipulating electricity flows to drive up prices. Only a deflated economy and dampened demand spared New York and other states with badly congested lines from similar woes. "A great deal of the market imperfections in terms of price spikes and the ability to game the



Power base: A training plane from Columbus Air Force Base flies above the flow cell battery building.



Energy pipelines: Workers weld support structures for 12 kilometers of electrolyte piping.



Pure juice: A fiberglass-reinforced plastic tank is part of an electrolyte system.



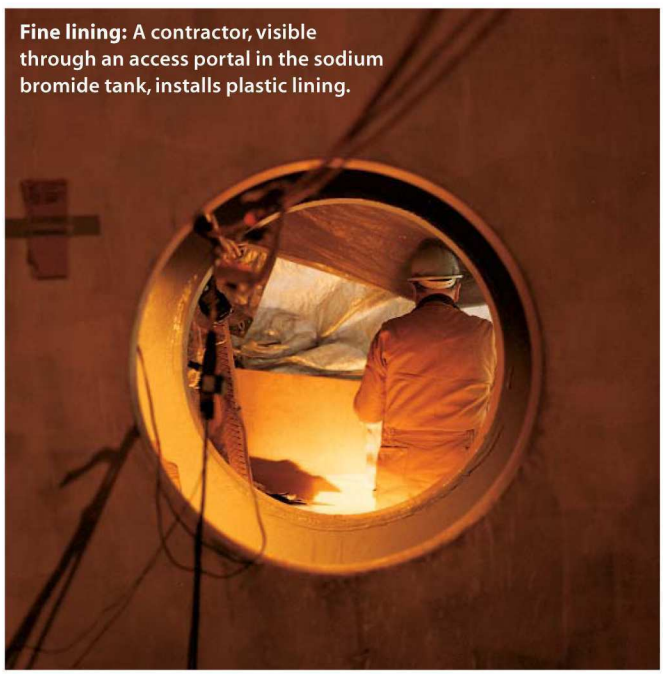
Belly of the battery: Inside a tank that will hold nearly two million liters of sodium bromide, labeled sections of a chemical-resistant plastic lining are installed.

market, the Enrons of the world, and so forth, are purely a result of the fact that we do not have large-scale storage capabilities distributed uniformly throughout the system," Yeager says.

Flow batteries offer a mechanism for providing that large-scale storage. You can put them in the plains of North Dakota or next to a power plant in New York City. Unlike conventional batteries, they can charge and discharge power without deteriorating. And unlike other energy-storage devices such as ultracapacitors and flywheels, which pack only enough energy to snuff out brief voltage fluctuations, flow cell batteries have the ability to store enough power to unburden a transmission line for several hours or to store gusts of nighttime wind power.

Like the fuel cells being developed for cars, the critical component in Regenesys's technology is a thin plastic film. By allowing only positively charged ions to pass through, this film choreographs an electrochemical dance in which electrons and positive ions jump between the battery's electrolytes, storing and then discharging electrical energy. The flow cell is so named because instead of holding the electrolytes inside as does a conventional electrochemical battery, the technology pumps electrolytes from separate storage tanks, and they flow past either side of the film *(see "Anatomy of a Flow Cell Battery," p. 52).*

Behind that seemingly simple operation is some advanced chemistry and plenty of plumbing. More than a decade ago, Regenesys's parent, U.K. power giant Innogy, licensed the rights to a particularly energetic pair of electrolytes, and it has been quietly designing flow cells ever since. The battery at Columbus Air Force Base and a sister facility Innogy is building next to a gas-fired power plant in Little Barford, England, represent the first large-scale construction of the technology. For maximum efficiency, each requires fabrication of 24,000 cells with films and electrodes that perform identically, a difficult engineering feat. And the film at the heart of each cell—a 60- by 90-centimeter sheet just one-half millimeter thick—must be precisely secured to ensure no leakage or tearing for the cell's anticipated life span, 15 years. Regenesys is making it all work on a large scale, says Joseph Hoagland, senior manager of clean and advanced energy



Fine lining: A contractor, visible through an access portal in the sodium bromide tank, installs plastic lining.

at the Tennessee Valley Authority's Public Power Institute, the research arm that directs the Columbus installation. "They are farther along in their development path in the sense that they have a much more sophisticated manufacturing capability on a large scale than the other companies," Hoagland says.

Regenesys expects to begin installing the flow cells at Little Barford this spring, and the Columbus installation should follow this summer or fall. If all goes as planned, Regenesys estimates that the Columbus plant will discharge roughly 60 to 65 percent of the electricity it absorbs. (The rest is spent to operate the plant's pumps or is lost as waste heat.) That power will serve the Air Force base and its neighbors after first passing through a circuit of high-voltage silicon switches that will transform the direct current that flows from the battery into a perfect wave of alternating current. The Regenesys plant may even be able to pump some power back into power lines that feed it, thereby dampening disturbances before they reach Columbus.

REALITY SHOCK

Making these giant batteries a widespread reality on the grid, however, requires presenting a compelling economic case to electric utilities. "The technology not only has to work. It has to work economically," says Hoagland. He estimates it will cost $25 million, or $2,000 per kilowatt, to build the Columbus battery. That's double the price of a new power line and diesel generators to back up the base. "They've got to be below $1,000 per kilowatt in capital costs before they're going to be something the utility industry is really going to take notice of," Hoagland says.

One thing sure to get the attention of power system operators is the potential of flow cells to save and even earn money by optimizing the use of existing power plants and lines. The Tennessee Valley Authority's studies show, for instance, that flow cells can pay back $250 per kilowatt per year if the cells enable power companies to buy electricity at a low price, store it, and later sell it at a higher price, while simultaneously providing power reserves and some stability control to local power lines. And in such congested electricity markets as Pennsylvania, New Jersey, and Maryland, deferring construction of a new power line by installing a flow cell instead could save more than $1,000 per kilowatt per year, says Joseph Iannucci, principal with Distributed Utility Associates, an energy consulting firm in Livermore, CA. By unclogging transmission bottlenecks while simultaneously playing the power markets, flow cell operators could not only make the technology practical, but also earn $4 billion in revenue annually in the United States alone, Iannucci maintains.

It sounds great, but the current regulatory climate is still murky for flow cells. Deregulation is separating the business of power generation from the business of shipping and distributing electricity, but the business of energy storage falls in a gray area somewhere between those two. Giant batteries affect distribution by unclogging bottlenecks on the lines, but they also act like power generators, supplying markets with cheap electricity from their stash of stored power. "Under the present uncertain semi-deregulated situation, it is very difficult to ask a utility to spend $25 million or $100 million on a storage system which tomorrow it may not be allowed to own," says American Electric's Nourai.

Nor is there much incentive for new entrepreneurial players to build flow cells. That's because deregulation has not yet introduced true competition in the transmission and distribution business. Upstarts who challenge the power industry with flow cells could easily be thwarted by the monopolies that control the power lines. "Even if my numbers show that the markets would be worth billions, who is going to take that risk?" Iannucci asks.

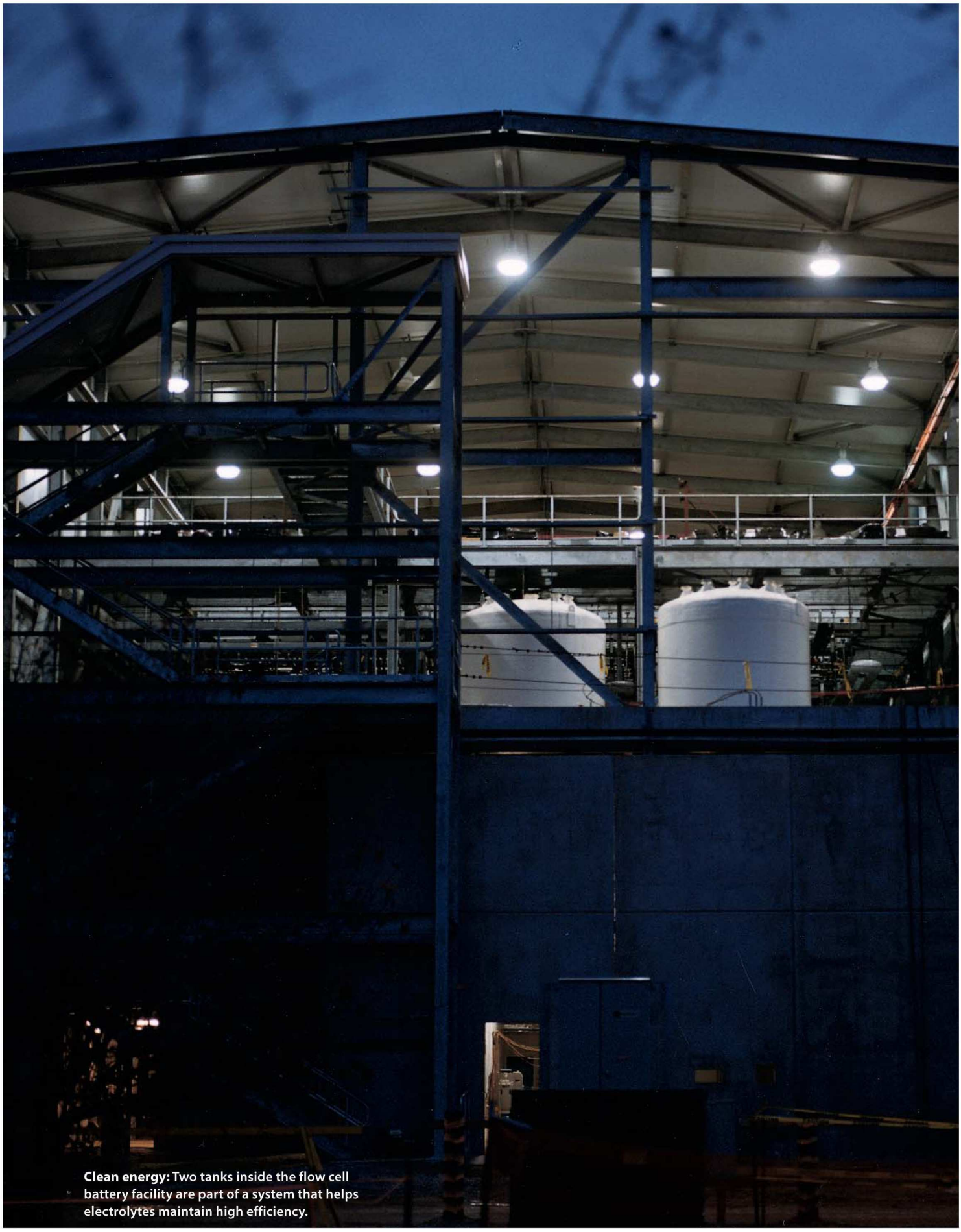
Much as they initiated competition in the power generation business in the early 1990s, federal energy regulators are now writing new ground rules that would unleash competition in the transmission markets. The regulators might, for instance, raise the cost of sending power through the most congested regions of the grid. Such so-called congestion pricing would stimulate investment in flow cells to relieve those costly bottlenecks.

Despite these uncertainties, there's little doubt giant batteries are coming. Favorable federal regulation could get them here sooner, but they'll get here in any case, says Imre Gyuk, who manages the U.S. Department of Energy's energy storage research programs. "As we get more and more congestion and it becomes more and more difficult to build new transmission lines, and as environmental constraints become greater…there will be a price crunch," says Gyuk. And then even the most costly grid battery will look attractive to transmission operators, he adds. "What is the price of air when you're being hanged? Or when you're drowning?"

Such morbid analogies don't sound too extreme to the engineers at Columbus Air Force Base. Last November two tornadoes tore through Columbus, shredding power lines and houses and plunging the city into 48 hours of darkness. The base lost power for three hours. That's not too long for most homeowners, but when it's a question of keeping jets aloft, three hours is an eternity. The base commander, Colonel Stephen Schmidt, says it seemed longer with the lights out, warning sirens inoperable, and no way to know when the next tornado might hit. "It would have been awesome if we'd been able to keep the power on," he says. In Columbus, at least, that ability is coming soon. TR

Battery Power for the Grid

COMPANY	PROJECT	TECHNOLOGY
Saft (Bagnolet, France)	Supplementary power source for Fairbanks, AK	Array of nickel-cadmium batteries to help provide steady voltage and supply energy
VRB Power Systems (Vancouver, Canada)	Backup power supply for Castle Valley, UT	Vanadium flow battery in lieu of upgrades to a 190-kilometer transmission line
ZBB Energy (Menomonee Falls, WI)	Solar-power delivery in White Cliffs, Australia	Zinc-bromine battery to store and deliver power from remote solar-power station
Active Power (Austin, TX)	Protection from faulty power in Rousset, France	Flywheel batteries to protect semiconductor factory against voltage fluctuations
Regenesys Technologies (Swindon, England)	Steady, reliable power source for Columbus, MS, and Little Barford, England	Flow battery using sodium bromide and sodium polysulfide to provide backup electricity



Clean energy: Two tanks inside the flow cell battery facility are part of a system that helps electrolytes maintain high efficiency.

HARNESSING QUANTUM BITS

COMPUTERS THAT EXPLOIT QUANTUM WEIRDNESS ARE FINALLY MOVING FROM IDEA TO IMPLEMENTATION, AND THEY ARE SPINNING OFF OTHER QUANTUM-SUPERCHARGED TECHNOLOGIES ON THE WAY.

BY MICHAEL HILTZIK

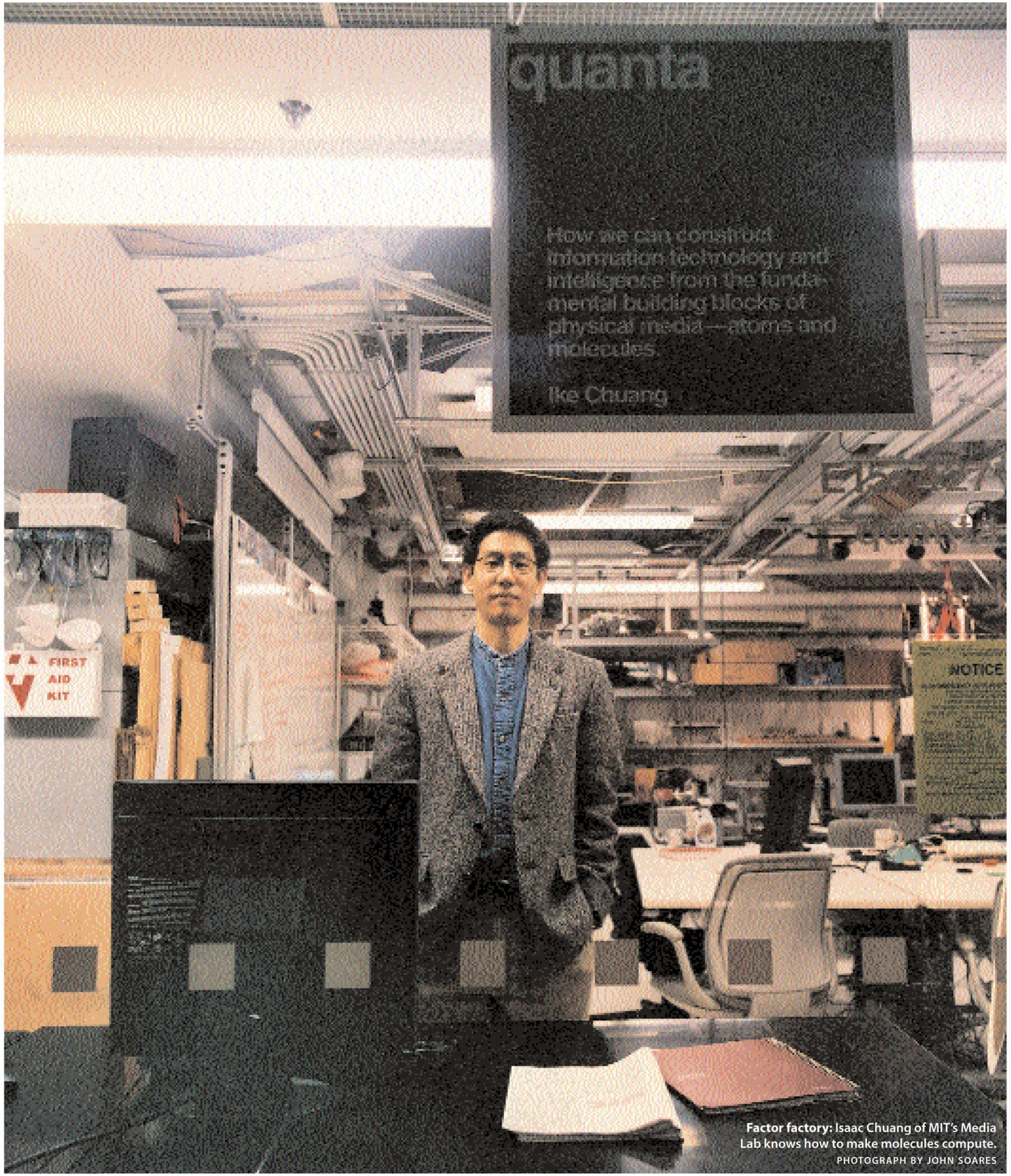
THE ACHIEVEMENT MAY NOT RANK UP there with Samuel Morse's transmitting, "What hath God wrought," from Washington, DC, to Baltimore in 1844 or Alexander Graham Bell's voice intoning, "Watson, come here. I want you," from one room to another in 1876. Nevertheless, scientists may eventually mark as a milestone the day in 2001 when Isaac Chuang and his colleagues at IBM determined that the two prime factors of the number 15 are three and five.

What made their calculation remarkable, of course, wasn't the grammar school arithmetic, but that the calculation had been performed by seven atomic nuclei in a custom-designed fluorocarbon molecule. The irony that an experiment so complex and delicate would yield a result so pedestrian and mundane is not lost on Chuang, one of the world's most prominent researchers in quantum computing. "My group," he says with a chuckle, "holds the world record for the largest and most useless quantum computer."

But Chuang, now an associate professor at the MIT Media Lab, might be showing an excess of humility. Quantum computers exist today only on a painfully small scale. But despite a slow start, the field seems to be on the verge of yielding real advances in quantum theory and engineering. Researchers have proposed the first designs for large-scale quantum computers, devices that use the bizarre properties of subatomic particles existing at the extremes of small size and high speed to solve problems that confound even the most powerful conventional computing devices.

One engineering approach with considerable promise employs a class of devices that can trap individual electrons within an electromagnetic field. Their "spin," or orientation in a magnetic field, can be observed to produce a quantum bit, or "qubit." Another promising approach uses nuclear magnetic resonance, which can manipulate collections, or "ensembles," of molecules to perform computations and return results in a measurable form. This is the technique Chuang and Neil Gershenfeld, a fellow MIT Media Lab professor, are exploring. "People are coming up with all these tools that will make a quantum computer easier to make," says Jonathan Dowling, principal scientist and supervisor of the quantum-computing technologies group at NASA's Jet Propulsion Laboratory in Pasadena, CA.

This research is also starting to indicate near-term spinoffs, including improvements in electronic controls for navigational, com-



Factor factory: Isaac Chuang of MIT's Media Lab knows how to make molecules compute.
PHOTOGRAPH BY JOHN SOARES

munications, and measurement devices. "One of the things I do is think of ways to use quantum computing to make better gizmos," says Dowling. Among his projects is a quantum gyroscope that would exploit the quantum behavior of photons to make these crucial navigation devices more sensitive. The excitement has spread even to the artificial-intelligence community: there are signs that the ability of quantum algorithms to probe multiple possibilities simultaneously might help in the mining of large-scale databases, one of the field's most important practical goals. If the geographic positioning systems, mobile phones, search engines, and integrated circuits of the future are vastly more precise or reliable than today's, it may be the result of trailblazing quantum-computing efforts under way right now in labs around the world.

The electronics industry, naturally, has taken notice. IBM sponsors quantum-computing research at its Almaden Research Center on the outskirts of Silicon Valley, where Chuang performed his initial work, as well as at its flagship Thomas J. Watson Research Center in Yorktown Heights, NY. Hewlett-Packard supports quantum-computing research at its labs in Palo Alto, CA, and Bristol, England. And the semiconductor industry, which has come of age along with advances in the electronics of classical computing, is keeping a sharp eye on developments in the field, the better to be prepared for the post-Moore's Law era, when miniaturization of classical electronic circuits bumps against physical limits. Experts predict that will happen sometime within the next two decades.

"Progress has been slow, but it's been steady," says David P. DiVincenzo of IBM's Watson lab. "Two or three years ago some significant efforts were started that are beginning to pay off."

For a time, scientists feared that the factoring problem would be quantum computing's only payoff. That was before they learned how quantum bits really work.

MULTIPLE REALITIES

WHATEVER THE TECHNOLOGICAL APPROACH, THE GOAL OF quantum computing is to take advantage of the very quality of quantum mechanics that designers of classical computers try mightily to avoid: its pure weirdness.

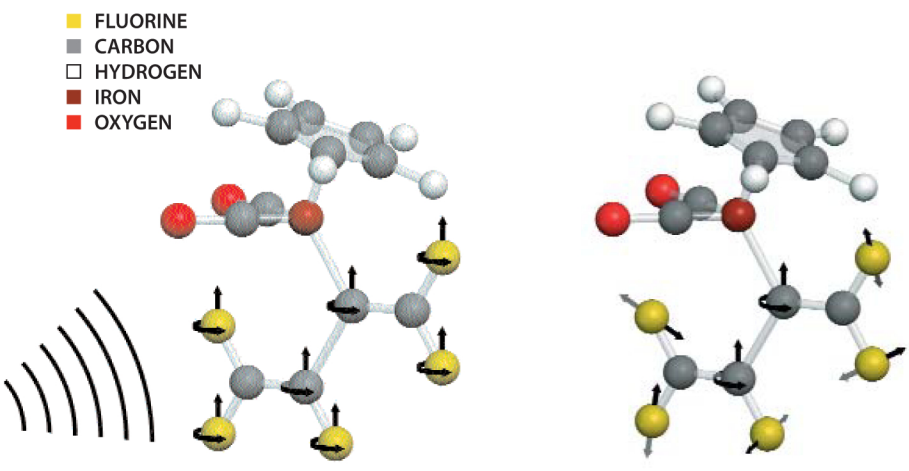
The logic circuits of traditional computers, for example, work by detecting discrete differences in the voltage passing through electronic gates: a high voltage indicates a binary one and a low voltage indicates a zero. Binary information can be represented also by the spin of an electron or the polarity of a photon. But because these particles exist in the quantum realm, which is marked by infinitesimally short distances, nearly speed-of-light velocities, and extremely low energy levels, their states can't always be discerned as strictly one or zero. Electrons and photons can behave like waves rather than particles, appear to occupy more than one place at a time, and simultaneously exhibit incompatible states: an electron's spin, for instance, can be both "up" and "down," a condition that quantum mechanics calls superposition. In computing terms, the qubit can be one and zero simultaneously.

The second phenomenon important to quantum computing is "entanglement," in which two or more particles are created with mutually dependent properties: when, for example, a single photon is turned into two complementary particles by an optical beam splitter. Measuring the properties of one particle instantaneously determines the state of the other, even if at the moment of measurement the two are separated from one another by galactic distances. (Einstein famously derided this phenomenon as "spooky action at a distance.")

It has long been believed that these phenomena could be employed to solve computational problems beyond the reach of traditional technology. A single quantum bit that can be in two states at once can do the job of two classical bits operating in parallel. (Only when the particle is measured or observed do all the possibilities resolve into a single, classical reality.) Two entangled qubits, meanwhile, can simultaneously evaluate four inputs. Put another way, a traditional memory register with eight bits can store only one of a possible 2^8, or 256, digital "words," but a quantum register with eight qubits can represent and compute with all 256 words at once.

Such general notions were articulated by Richard Feynman, among others, as long ago as the 1980s. For years, however, no one had a clear idea how they might be applied to real problems. In 1994 mathematician Peter W. Shor of AT&T Bell Labs described an algorithm,

The Seven-Qubit Computer



BEFORE: The nuclear spins of certain atoms in Chuang's fluorocarbon molecule are aligned with an external magnetic field—their spins are "up"—and represent digital ones. A sequence of radio pulses strikes.

AFTER: The pulses force the spins of the fluorine atoms into a state that is simultaneously "up" and "down"—representing binary ones and zeroes. These quantum bits can now interact to carry out computations.

JOHN MACNEILL



Getting centered: NASA's Jonathan Dowling is building a quantum gyroscope that will help spacecraft navigate more precisely.
PHOTOGRAPH BY MISHA GRAVENOR

or program, that proved a quantum computer could factor large numbers exponentially faster than any known conventional method.

Shor's discovery was important because factoring is exactly the kind of problem that overwhelms conventional computers: As a number grows larger, the resources required to factor it expand rapidly. To factor the number six is trivial, but experts estimate it would take all the supercomputers in the world longer than the age of the known universe to find the factors of a number with 300 digits.

Factoring, moreover, is a mathematical problem with real-world applications. The very intractability of large-number factoring is at the core of modern cryptography, which relies on it to create unbreakable keys. Shor's algorithm represented both a dagger in the heart of old-style "unbreakable" codes and a signpost pointing toward a new class of truly unbreakable codes. Indeed, many quantum-computing experts predict that quantum cryptography will be the first commercial application to emerge from the fledgling science, and already at least three companies have been formed to market secure communications systems based on quantum factoring *(see "Quantum Cryptography,"* TR *February 2003).*

BEYOND SECURE CODES

AT THE SAME TIME, SHOR'S WORK PROvoked a surge of interest in other possible applications of quantum computing. "After the first result from Shor," says computer scientist Wim van Dam of HP Labs, "everybody was very optimistic that we'd find lots and lots of algorithms" for which quantum computing would be useful. But through most of the 1990s, such "killer apps" remained elusive. For a time, scientists feared that the factoring problem would be quantum computing's only payoff.

In the last two years, however, an improved understanding of how qubits work has stimulated a new search for problems qubits are particularly well suited to solve. Edward Farhi of the Center for Theoretical Physics at MIT is among those who have undertaken that work. "The whole focus of our interest," Farhi says, "is if you had a perfectly functioning quantum computer, what would you do with it?"

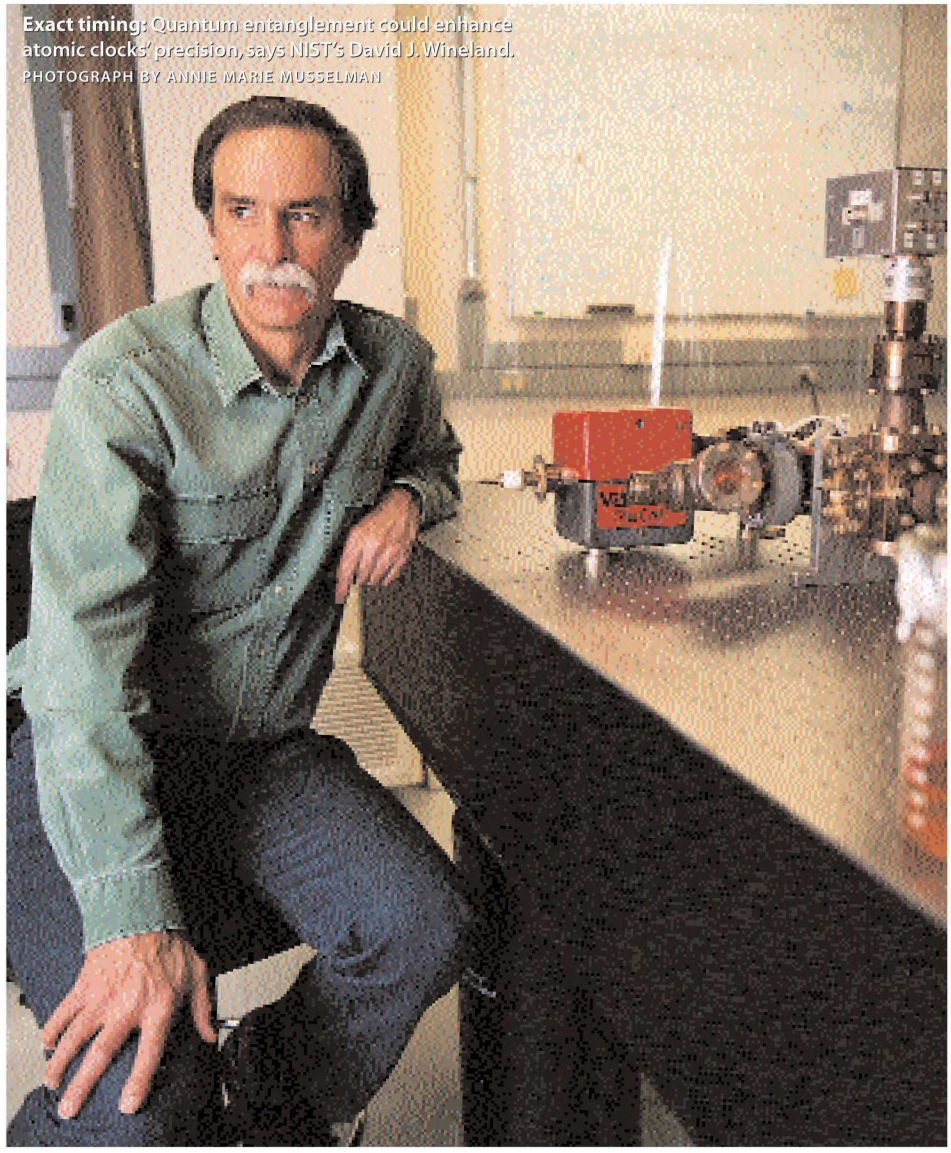
Farhi and his colleagues have identified a range of general, if abstract, computations quantum computers can complete far faster than classical computers. One is a navigation problem in which a traveler with neither map nor guide moves from starting point to destination via random paths that branch from a given number of way stations. Surprising nobody, Farhi's team showed that under such conditions, the time a classical computer requires to find a way from point *A* to point *B* expands exponentially as the number of branching points between *A* and *B* increases. In contrast, a quantum computer would travel all possible paths at once, reliably finding its way across the maze in a time frame that expands only arithmetically with the complexity of the maze.

"I'm kind of pleased with this thing even though it's a bit artificial," Farhi says. What distinguishes Farhi's problem from the famous "traveling salesman" problem and other logistical conundrums is that the traveler has no map and therefore only limited knowledge of the pathway. But in the real world, a traveler is likely to have a map showing all possible paths, and the challenge is to find the most efficient route. All a quantum computer does is traverse all paths at once to quickly arrive at the destination—but it won't produce a particular route. So it isn't yet clear whether or not Farhi's work points to a practical application. "This is a steppingstone to a better example," Farhi says hopefully. "I guess you could say we're looking for a…real-world example."

A more likely use of quantum computing may be in database searches. In 1996 Lov Grover, a physical-sciences researcher at Lucent Technologies' Bell Labs, developed an algorithm that showed how quantum computing could vastly accelerate

searches: A classical computer searching a phone book with, say, one million entries would average some five hundred thousand tries to find a single specified phone number. A quantum computer would need only one thousand tries.

"The point is," Farhi says, "quantum speedup is not universal. So finding problems for which it's advantageous is an art."



Exact timing: Quantum entanglement could enhance atomic clocks' precision, says NIST's David J. Wineland.
PHOTOGRAPH BY ANNIE MARIE MUSSELMAN

QUBIT TRAPPERS

WHILE FARHI AND HIS COLLEAGUES ARE determining what can be done with a quantum computer, others are hard at work engineering the hardware itself.

IBM's DiVincenzo says a practical quantum computer must have five fundamental capabilities: It must provide for qubits—particles or groups of particles that can be isolated and placed in superposition, the indeterminate state in which they represent both ones and zeroes. It must be possible for operators to control the initial states of the qubits, analogous to setting them all to zero at the outset of a computation. The qubits must remain stable—in superposition long enough to perform an operation—anywhere from milliseconds to several seconds. It must be possible to implement quantum logic circuits that correspond to such Boolean operators as *and*, *or*, and *not*, which form the basis of traditional computer architecture. In classical computers these expressions are embodied in electrical circuits. The simplest logic gate, the *not* gate, converts an incoming digital one into a zero, and vice versa. To manipulate qubits, quantum circuits will have to employ techniques such as extremely precise control of magnetic fields or laser pulses.

The final requirement of a quantum computer is that it make the results of a calculation accessible to the user, through, for example, a visual readout.

Most quantum-computing experiments boil down to efforts that address one or more of DiVincenzo's requirements. "There are probably a half-dozen serious proposals and 10 times that number that are not serious," says Bruce Kane, who specializes in the science of single-electron devices at the University of Maryland.

Chuang and Gershenfeld, for example, used nuclear magnetic resonance to measure the spin of qubits in bulk materials—a vial containing a billion billion molecules custom-made from fluorine, carbon, iron, hydrogen, and oxygen. The spins of the nuclei of the five fluorine and two carbon atoms in each molecule functioned as interacting qubits to execute Shor's algorithm. Although Chuang and Gershenfeld's achievement in controlling and measuring the spins of seven qubits has been widely hailed, many in the field believe that scaleup of this approach will be extremely difficult. "The limitation is that every time you add qubits…the signal-to-noise ratio decreases," says Kane, referring to the amount of useful information—such as the excess of particles with one spin over particles with a different spin—that can be distinguished from random disturbances in the bulk fluorocarbon material.

Chuang himself acknowledges that his seven-bit quantum computer falls far short of the scale needed for meaningful computations. "To make it practical, we'll have to get to thousands, if not hundreds of thousands, of qubits," he says. A rival approach that uses nanoscale engineering techniques to build qubit containers, he adds, may be easier to scale up.

David J. Wineland and his team are studying this alternative at the Time and Frequency Division of the U.S. National Institute of Standards and Technology in Boulder, CO. They're building miniature devices using electrodes that isolate ions in "traps" fashioned from electric fields. The virtue of this approach, Wineland says, is that ion traps are relatively easy to fabricate, may be linked together, and can hold more than one ion per trap. Wineland suggests that a string of ions confined in a single trap might function as a sort of quantum memory, and each additional qubit would expand storage capacity exponentially.

Already, Wineland's group has coaxed such qubits to stay in a state of superposition for up to 10 minutes. But one current weakness in this scheme is that it's difficult to transfer quantum information between ions held in separate traps, a necessity for large-scale computations.

QUANTUM SPINOFFS

CREATING QUBITS THAT INTERACT AND STAY IN SUPERPOSITION long enough to make themselves useful will preoccupy quantum-computing researchers for years to come. Still, practical payoffs are emerging as scientists exploit the phenomena behind quantum computing in related fields.

At NIST, whose institutional mission includes setting standards for the measurement of time, Wineland's interest in quantum computation predated even Shor's algorithm. "We were starting to think up ways quantum entanglement could be used to improve the signal-to-noise ratio in atomic clocks," he explains. "We knew there was a quantum entanglement state that could improve the clock, and the ideas of quantum computation showed how to make it." Roughly speaking, today's atomic clocks work by taking the average of simultaneous readings of the oscillating magnetic fields of more than a million cesium atoms; quantum entanglement could reduce the time needed to compute that average and enhance precision by allowing many readings to be taken concurrently.

The Jet Propulsion Laboratory's Dowling adds that quantum entanglement may provide a better way to synchronize earthbound clocks with those in space. At present, ground-and-space synchronization, which is most often done by radio, is thrown off, albeit minutely, by atmospheric refraction and other effects. Because entangled photons are linked on a quantum level, they are immune to these physical disturbances. "It would be a really big deal to knock those [effects] out," Dowling says. He suggests sending entangled particles to the sites to be synchronized. Measuring one particle would instantaneously set the other one to "ticking," Dowling says. Having calibrated their clocks to the ticking particles, operators would know the clocks were in agreement.

Lest anyone think that quantum-scale refinements of time measurement are of academic interest only, it should be noted that atomic timekeeping is the basis of geographic positioning systems, satellite tracking technologies, and mobile communications networks, which are synchronized by the second. "History has shown forever that whenever there's a better clock, it gets used," Wineland says. "It's a good bet that trend will continue."

Scientists in industry, meanwhile, are looking for ways to bootstrap quantum computing by linking it with conventional technologies in which they have more experience. Last year Hewlett-Packard forged a $2.5 million working alliance with Gershenfeld and Chuang to, as HP Labs senior scientist Philip Kuekes says, "combine our respective expertise." HP is intrigued, for instance, by the possibility of transmitting quantum bits via ordinary fiber-optic lines—thousands of kilometers of which lie installed but underutilized around the country. "That's actually quite interesting," Kuekes says. The long-distance transmission of quantum information, enhanced by the characteristics of quantum entanglement, would allow correspondents to share code keys without fear of their being compromised. That means, he adds, that "one of the things that might happen quite early is quantum cryptography."

Although, as research has shown, qubits can be transmitted over fiber-optic lines, the transmissions work for no more than tens of kilometers at a time. Sending qubits across continents or oceans, Kuekes says, would require a system of quantum switches and repeaters analogous to the solid-state versions that help move data throughout the Internet. These would amount to simple quantum computers equipped with error-correcting software that could compensate for the inevitable loss of superposition among many of the traveling qubits. Development of this software is one of the main thrusts of HP Labs' research.

In a scientific example of the child's being father to the man, applied research has thrown off some ancillary benefits even in the parent science of quantum mechanics. The tools needed to perfect quantum computing, it turns out, also help demonstrate particle behavior that physicists, until now, have posited only in theory.

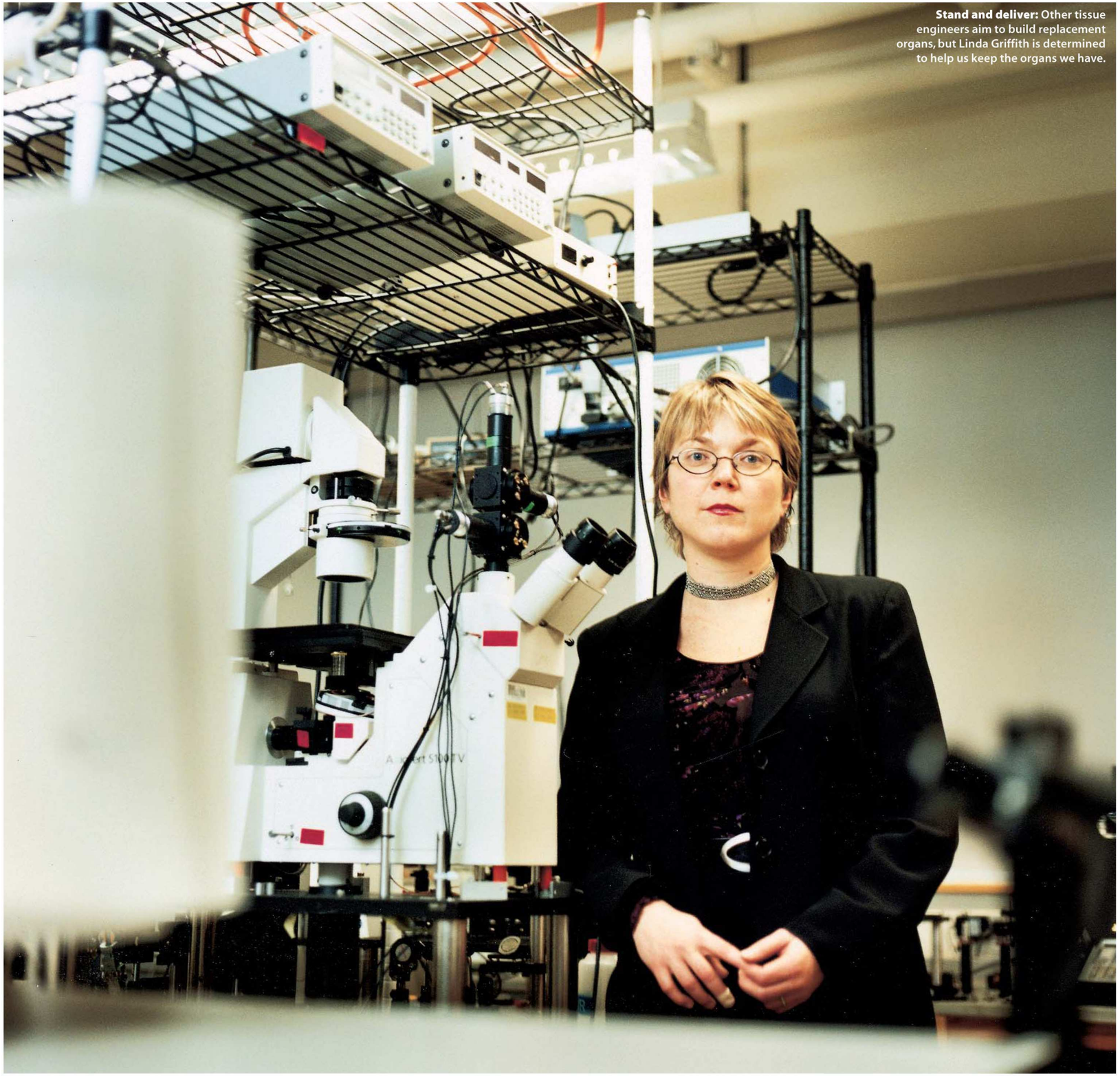
"There's a beautiful flowing-back the other way," says John Preskill, a professor of theoretical physics at Caltech. "Interest in quantum computing has inspired a lot of interesting science. We're a long way from a crash program in engineering, but we're entering a new era in condensed-matter physics."

This is largely a result of quantum computing's requirement that qubits be controlled and measured with unprecedented precision. "The tradition in condensed-matter physics has been to do experiments on ensembles," that is, huge quantities of atoms whose quantum behavior can be identified statistically, Preskill says. "You don't ordinarily measure the behavior of single electrons."

The tools needed to perfect quantum computing, it turns out, also help physicists observe the behaviors of individual particles—phenomena once known only in theory.

In particular, Wineland's experiments at NIST, Preskill says, have given physicists an unparalleled window on the behaviors of individual particles. The breakdown of qubits into classical ones or zeroes, for example, is a phenomenon that, in the past, scientists could only infer by observing whole clouds of electrons or photons. The clouds' average signal would indicate whether some particles had changed their quantum state, "but you wouldn't really see the individual particle behavior," Preskill says. "It really is a new type of experiment."

Preskill, like others in the field, cautions that many questions need to be answered and critical problems resolved before quantum computing can advance beyond its current elementary applications. "Whether this field will still look this exciting in 10 years, I can't say," he admits. "But for now, the field feels fresh and new." Once again.



Stand and deliver: Other tissue engineers aim to build replacement organs, but Linda Griffith is determined to help us keep the organs we have.

LINDA GRIFFITH IS BUILDING TINY HUMAN LIVERS ON SILICON CHIPS. THESE LIVERS AREN'T REPLACEMENT PARTS, THOUGH. THEY'RE THE CORE OF A SYSTEM THAT COULD REVOLUTIONIZE MEDICAL RESEARCH.

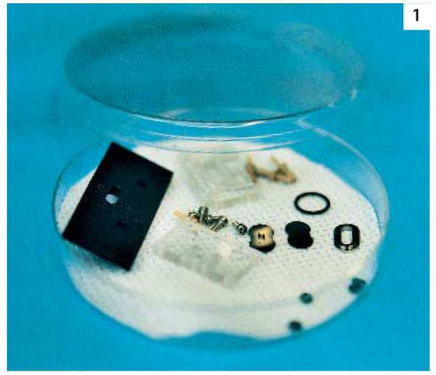
THE LIVER CHIP

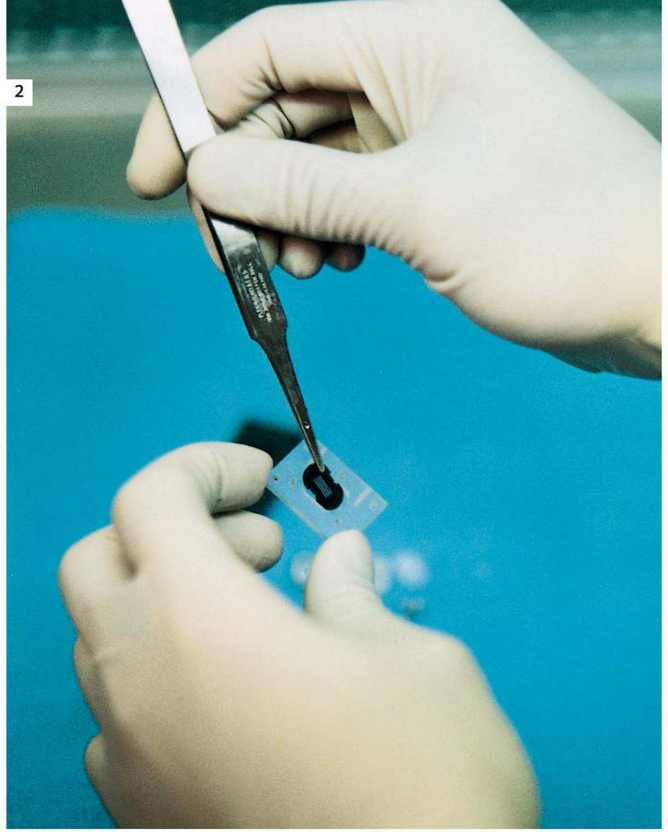
PHOTOGRAPHS BY KATHLEEN DOOHER

DEMO

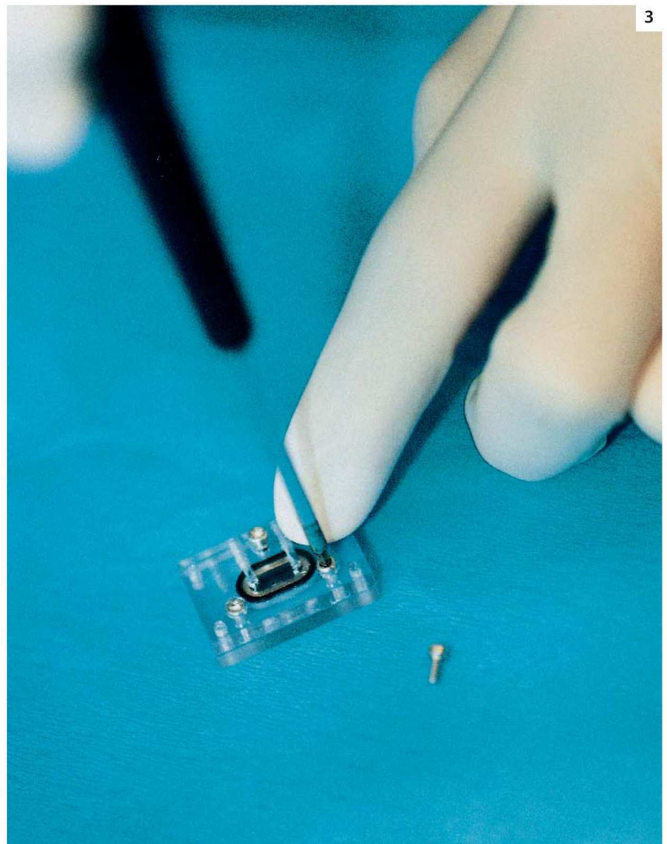
Several years ago, MIT tissue engineer Linda Griffith set out to build an artificial liver that could eliminate the need for donated organs for transplant. Then she had a realization: the most common reason for needing a liver transplant is a hepatitis C infection, and "if it were me, I'd rather not *have* a liver transplant. I'd rather the doctor said, 'Here, take these drugs; you will be cured of hepatitis C; you'll go on and lead a happy life; and you'll stay out of the operating room.'" But researchers have a hard time developing drugs for hepatitis C and other ailments because animal experiments don't always reveal what happens in humans, and human cells in a petri dish don't always function the way they would in the body. Indeed, hepatitis viruses don't even infect human liver cells in a petri dish. So Griffith and her team are putting their tissue-engineering expertise to work building what's essentially a miniature human liver on a silicon chip. It won't serve as a replacement part but rather as an amazingly realistic model of the natural organ. "What we're trying to do is replicate the structure, as well as the mechanical forces, so that we can hopefully replicate the function," she explains. Mass produced, such a chip could be a boon not only to companies developing drugs for hepatitis and other diseases, but also for scientists investigating liver cancer and gene therapy, and even chemical firms testing the toxicity of new materials. Griffith and graduate student Albert Hwa showed *Technology Review* senior editor Rebecca Zacks how to build a little liver.

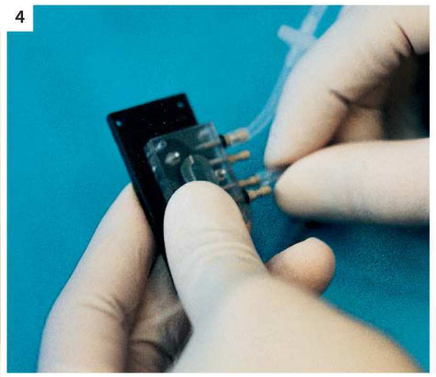
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1-2. The liver chip is constructed of two very thin peanut-shaped pieces of silicon assembled in a plastic housing. Hwa pulls out a petri dish containing those parts, along with all the gaskets and screws needed to hold the system together. As he lays the first silicon piece into a cavity within the housing, he points out its 40 tiny channels. The walls of these "wells" have been chemically modified to grab onto a protein called collagen, Hwa says, which in turn provides the liver cells a place to anchor themselves. Hwa adds a filter, which keeps the cells in the system long enough to latch on, then the second silicon piece, which is for support.

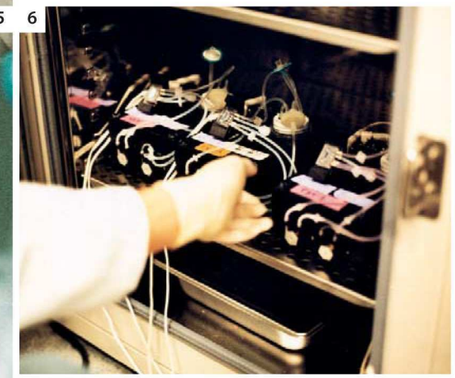




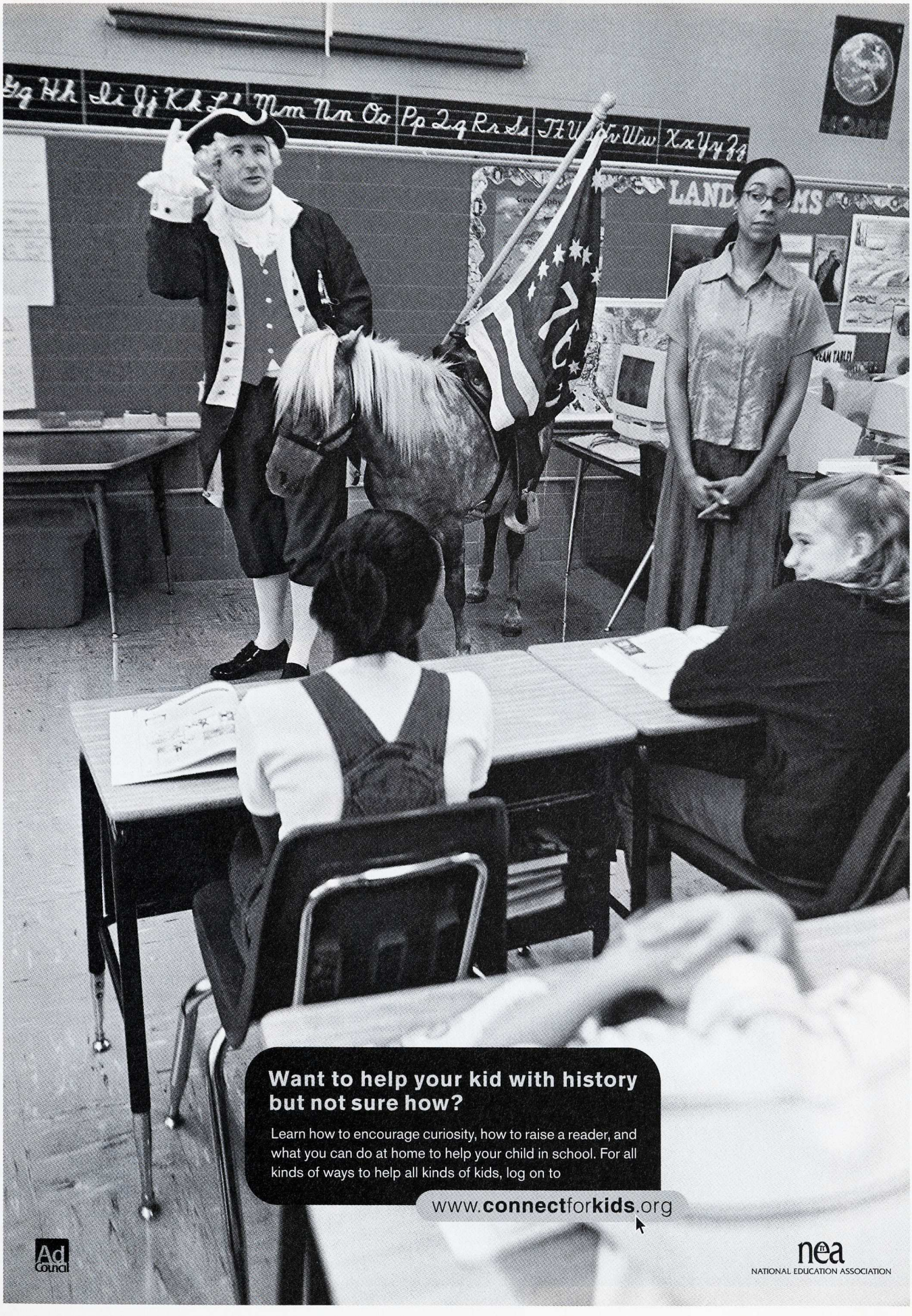
3-4. Once all the pieces are in place, Hwa closes the housing with four tiny screws, creating a tight seal. He then attaches four plastic inlets that will allow fluid that bears oxygen and nutrients to flow through the wells' centers. A pump keeps the fluid moving through the system, much as the heart keeps blood flowing through the body. This creates a more natural environment for the cells. In conventional experiments, cells simply sit in petri dishes full of a nutrient solution. But, Griffith says, "part of what influences how tissues function in the body are mechanical forces: some of those come from blood flowing through the tissue."



5. Once he has primed the system with the nutrient fluid, Hwa detaches the inlets from the black loaf-pan-size pump and attaches a syringe full of liver cells. Gently, he squeezes in the cells, using a second syringe to regulate the pressure in the system. In early work on the liver system, Griffith's team simply added hepatocytes—large cells that are the central players in the liver. But Hwa is experimenting with additional cells that, in the body, help form structures such as blood vessels. "Tissues have a very exquisite structure," Griffith explains, "where there are different kinds of cells that reside right next to each other, and there's constant communication between these different cell types. So when we take cells out of the body and put them in culture, we lose a lot of that structure, and presumably that's why we lose some of the function as well." The researchers hope the right types of cells will work together to create a more accurate model of the liver.



6. Hwa reattaches the pump and puts the whole apparatus into an incubator that closely controls the temperature, humidity, and concentrations of oxygen and carbon dioxide. With the right conditions, the cells do the rest, assembling themselves into structures similar to those of natural liver tissue. Since each miniature liver can live for weeks in the incubator, the researchers can conduct a variety of tests. The thin wall of the plastic housing allows them to monitor the tissue under a microscope, and a portable suitcase-size contraption controls environmental factors when the scientists need to take the liver chip out of the incubator for long periods. Griffith's team is now working to make the system available to researchers in a number of industries and academic fields. With funding from DuPont and others, Griffith says, "what we're trying to do is put together enough people who want to use the system that we could make it disposable and user friendly." And that could make the liver chip a lab staple. TR


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By David Talbot
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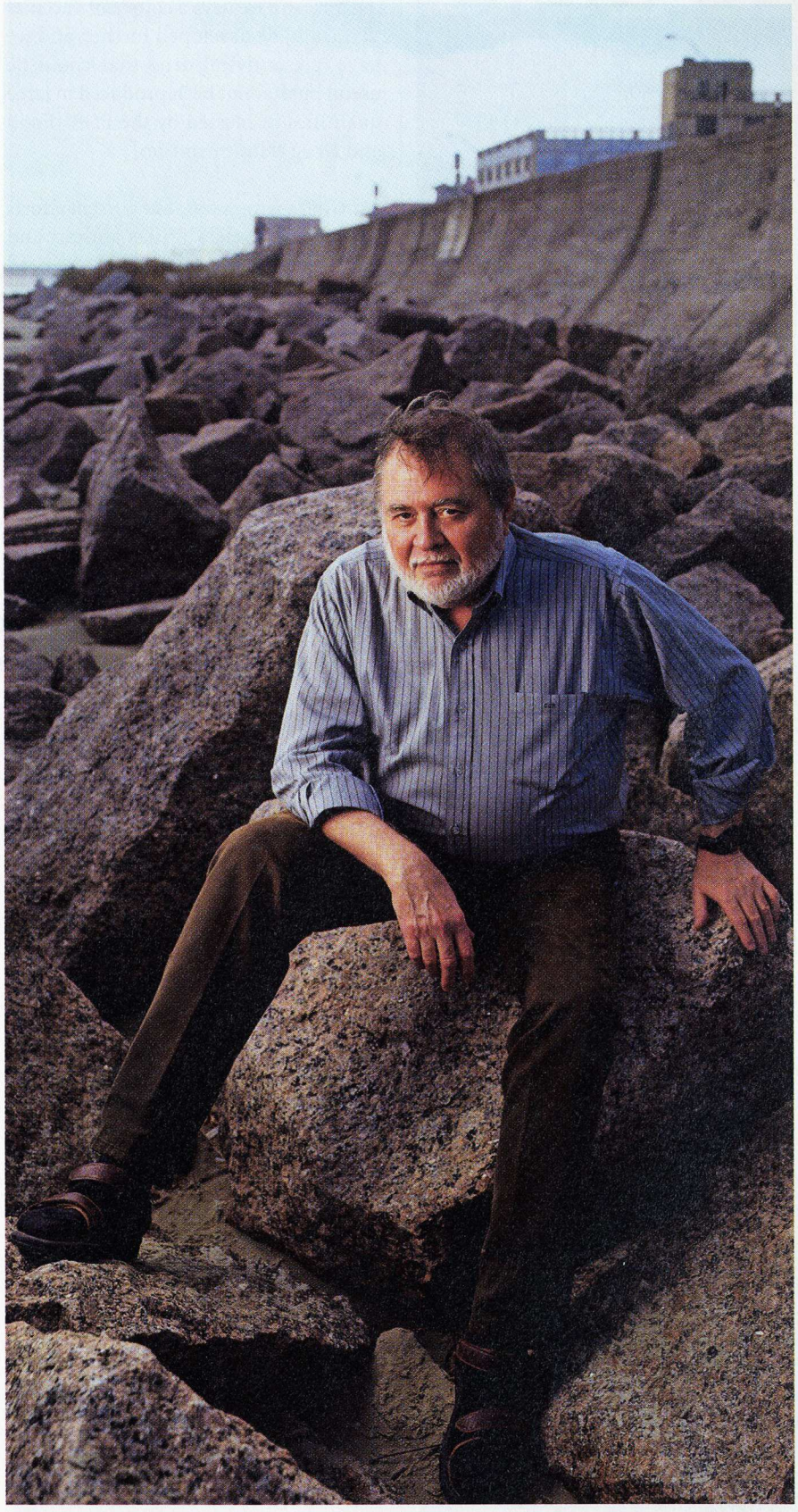
FINDING AN ANTIDOTE TO BIOWEAPONS

C.J. Peters

POSITION: Director, Center for Biodefense, University of Texas Medical Branch at Galveston, TX

ISSUE: Bioterrorism preparedness. We need to ramp up development of life-saving vaccines and drugs to protect ourselves from attacks with anthrax, smallpox, and other life-threatening bioweapons.

PERSONAL POINT OF IMPACT: Former chief, Special Pathogens Branch, National Center for Infectious Diseases, Centers for Disease Control and Prevention



TECHNOLOGY REVIEW: What are the worst bioweapon threats? How prepared are we?

C.J. PETERS: Inhalation anthrax is one of the highest threats. Manufacturing stable material for a weapon is easier with anthrax than with other bioweapons. Plus, we have both the threat of antibiotic-sensitive anthrax, which is huge, and also the threat of antibiotic-resistant anthrax, which would be even worse. We know that antibiotic-resistant anthrax is easy to make. It's been done. It's in the literature. The Soviets claimed they made anthrax resistant to six different classes of antibiotics. Anthrax properly prepared and introduced into the ventilation system of a large building that might have thousands of inhabitants could kill virtually all of them. And you could repeat this building by building, or in a subway, or in a closed arena.

But other agents, if they're in a state-sponsored program, are also a huge threat. First of all, the viruses can be grown in animals, so you don't need a bunch of high tech cell cultures. We need to understand these agents better, particularly the agents that are natural disease problems. With hemorrhagic fevers like Ebola, you've got lethal agents for which there's very little, if any, therapy. Our preparedness on these fronts is still



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in the fantasy stage. We need to be moving forward: we have a couple of vaccines that could be developed further, and we have one antiviral drug that could be useful but has not been produced in large quantities or blessed by the FDA [Food and Drug Administration].

TR: What's wrong with our current efforts to protect ourselves against anthrax and other bioweapons? And what do we need to do?

PETERS: We need to improve how we develop drugs to treat the effects of bioweapons. Our pharmaceutical industry and national health research systems aren't set up to do this. In the past, if we had a disease, the CDC went out and defined the threat. They would tell you, Here's polio, or, Here's measles, and so on.

You've got lethal agents for which there's very little, if any, therapy. Our preparedness on some fronts is still in the fantasy stage. We need to be moving forward.

Then the NIAID [National Institute of Allergy and Infectious Diseases] would develop the science to make a vaccine or other remedy possible. And then industry picked it up and manufactured it because it was profitable, and it was the thing to do. With bioweapons, the CDC doesn't know what the threat is any more than anybody else. We have the intelligence community telling us, and we're not used to that. The National Institutes of Health is sponsoring a lot of research, but industry is not going to pick these things up. It's just not going to. But let's don't beat up on the pharmaceutical industry. The industry was set up to make profits; it will spend a lot more effort making Viagra than thinking about anthrax. So we need a model where NIAID can contract directly or indirectly with industry or somehow find a way to motivate industry to pick these items up and actually develop them.

Inhalation anthrax is a great example of this; it's a very rare disease naturally, so there haven't been any drugs made specifically to treat it. Anthrax can be treated in early stages with antibiotics developed for more common infections. But anthrax toxins go on acting after we treat the bugs themselves. We don't have any approved treatments for those toxins. Research at Harvard and several other places has indicated some of the ways to go: striking at the toxins, binding them up, neutralizing them. We should sort through those approaches and get some of them out on the shelf where physicians can use them.

TR: What changes would help us better develop drugs against bioweapons?

PETERS: The good news is NIH is getting a huge boost in funding for biological-defense-related work. And [NIAID director Anthony] Fauci has made a very important statement: there will be an effort to have financing that provides a stable and adequate financial motivation for industry. I think this is the right path, although it may need either more bucks than we are ready to ante up or even some sort of stick, saying, You do it, or we will go outside the paradigm. Meaning that the federal government would manufacture the remedies itself, spawn new companies, or otherwise influence the big drug companies to undertake the mission.

TR: These are long-term solutions that will obviously take years. What can we do more immediately to prepare the nation?

PETERS: We need to get diagnostics out to the emergency room level for all the biowarfare agents, so we can diagnose people directly—not at CDC headquarters in Atlanta a week later when someone thinks about it and mails a sample to Atlanta. That way we can test anybody who looks sick with something that is hard to explain. Right now we don't have that capability. The technology exists. In many cases it could be done, but we don't have the actual machine that can do it for us. We need to develop that platform and get it out into the emergency rooms.

TR: What about smallpox vaccinations? Do you think parents should vaccinate their children against smallpox?

PETERS: No, I would not suggest they do that. The vaccine is overall a good vaccine. But as with all vaccines, some people will be hurt. So we should not vaccinate the general population until the threat is higher.

We're actually getting close to being ready on smallpox. We've got enough vaccine. We have some plans as to how to give it. We now have a decision to go ahead and vaccinate medical staff most likely to see the first cases. And we could respond to an outbreak right now. Maybe not as well as we'd like to. We're a year away from being in as good a position as the currently perceived threat suggests we should be. But today, we're still in a pretty good position.

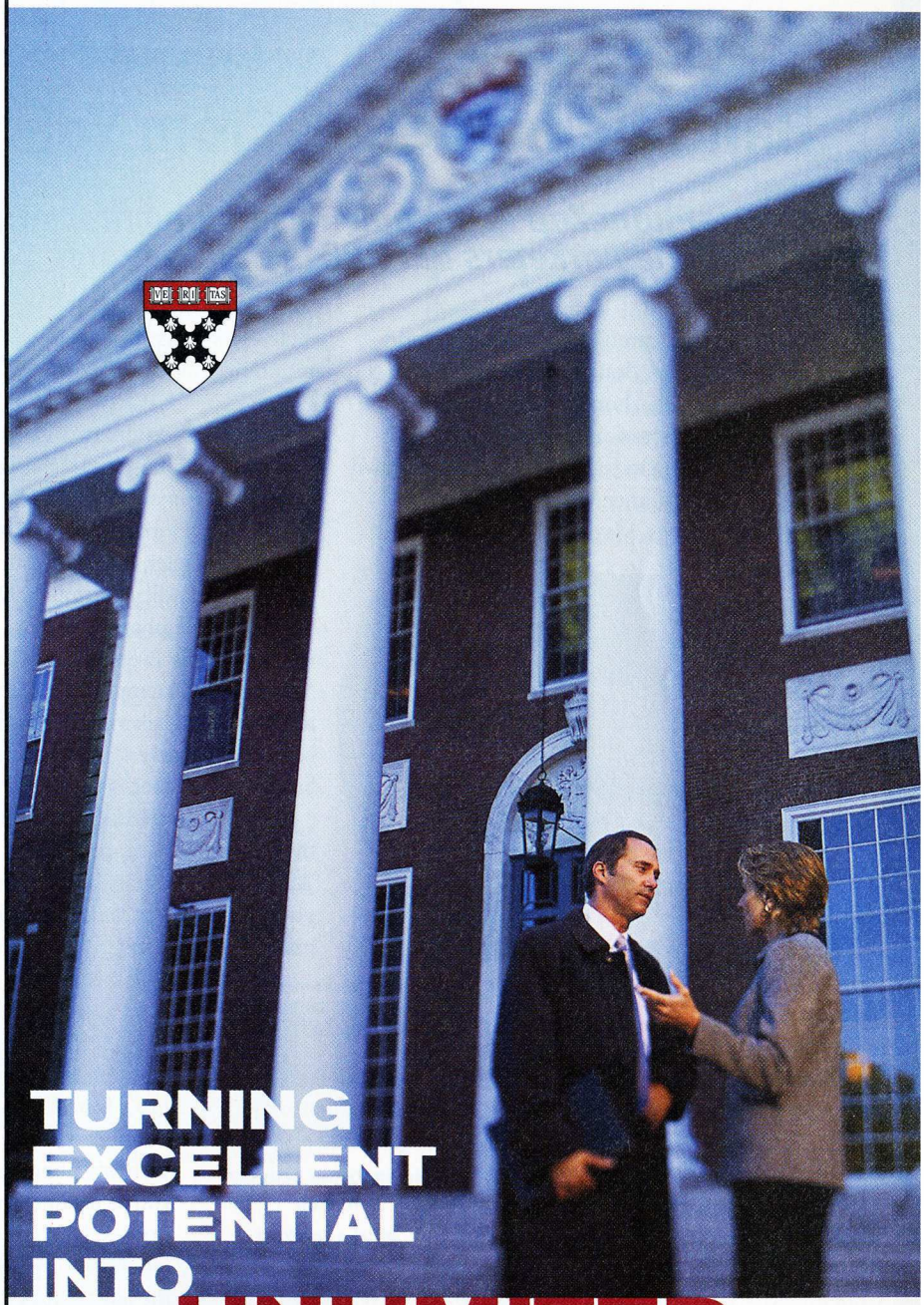
We're not ready for every scenario, of course. The old Soviet plan was to use tons of smallpox delivered by missiles and cluster bombs and literally saturate urban areas with smallpox. So you'd have lots of direct infections followed by the contagion. We're not ready for a massive attack of that nature. But I don't think we're concerned about the former Soviet states mounting it. And I don't think other state actors have that kind of capability.

TR: Are we ready for a genetically engineered superstrain of a bioweapon such as vaccine-resistant smallpox?

PETERS: I don't think engineered smallpox is a real consideration right now. Genetically modifying viruses and knowing what's really going to happen when they're modified—whether it's really going to work—that's a lot harder than making antibiotic-resistant bacteria.

But I don't think it will always be that way. The future will be more dangerous if current trends continue. We're going to have to be thinking that people will be trying different things, looking for ways to get around vaccines or drugs. And we have to be thinking about how they might do it; how we can counter it. Above all, we have to have the intelligence out there to find out about it. TR

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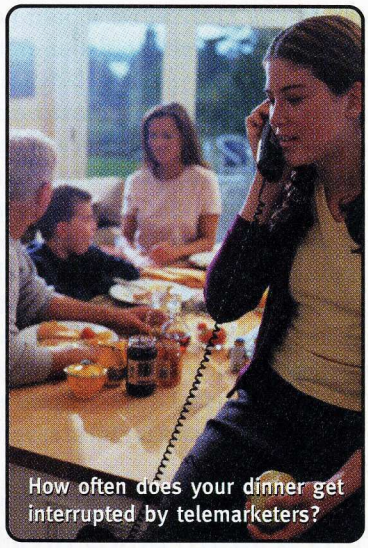
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By Tracy Staedter

IRIS IDENTIFICATION

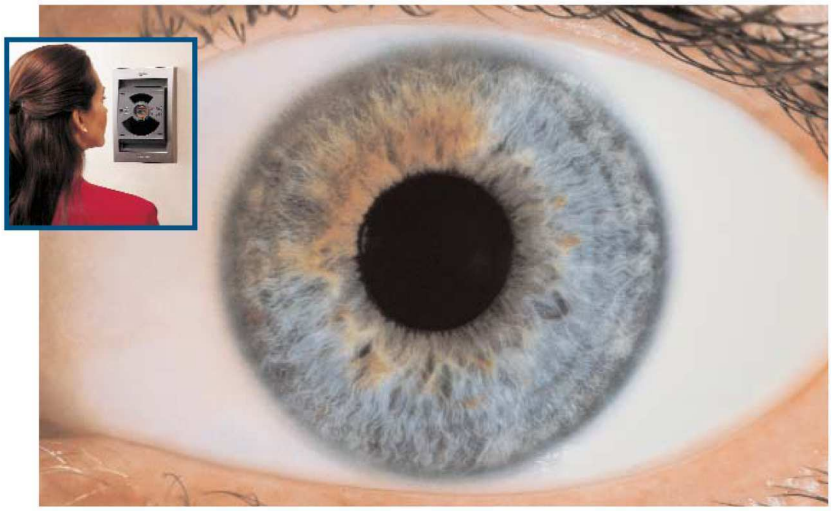
At airports around the world, certain international travelers frequently cross borders without passports. They rely instead on a new security system that confirms their identity by looking into their eyes. These iris recognition systems are already proving effective at London's Heathrow Airport and Amsterdam's Airport Schiphol, and they are scheduled for installation this year at 11 Canadian hubs.

Not to be confused with retinal scanning, which focuses on the pattern of blood vessels in the back of the eye, iris identification works by noting the distribution of distinguishable characteristics—striations, pits, filaments, rings, freckles, and darkened areas—within the eye's colored membrane. The systems examine the iris with infrared light that reduces reflections and penetrates glasses and contact lenses, preventing such eyewear from interfering with recognition. The technology was first studied in the 1930s, and thanks to algorithms developed by John Daugman, a computer scientist at the University of Cambridge in England, it became feasible in the 1990s. Iridian Technologies in Moorestown, NJ, owner of Daugman's patents, licenses them to such companies as IBM, Panasonic, and EyeTicket in McLean, VA.

Iris identification is highly accurate. The technology measures more than 250 distinct features. Fingerprint analysis, by comparison, usually captures 40 to 60. In 2001 the National Physical Laboratory, the U.K. standards lab, used Daugman's algorithms to compare more than two million samples. The iris system produced no false matches, establishing its superiority to all other biometric systems on the market. And because no two irises have yet been shown to be identical, the chance is about one in a million that a person would be mistakenly identified, according to Iridian Technologies.

When it comes to biometric security, one might say, the eyes have it. TR

For an animated version of this illustration, go to www.technologyreview.com/visualize/.



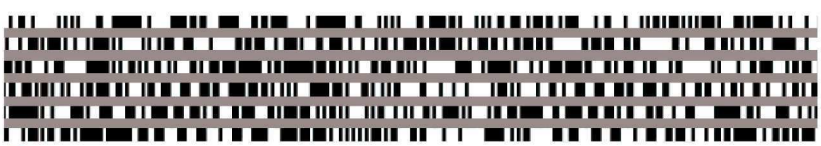
1 A person using an iris identification system stands in front of the unit (inset) while infrared light illuminates the eye. A camera photographs the iris (above). Software distinguishes the shape of the iris relative to the eyelid.



2 Software "unwraps" the donut shape of the iris so that it occupies the space of a rectangle.



3 The program places a grid over the iris pattern. At each point, computer algorithms extract a numeric value for more than 250 variables that include phase, magnitude, and location of features.



4 The values are converted into a binary IrisCode. The unique code is assigned to the person and is used later for comparison purposes whenever the person approaches the security system.

STONE (IRIS); SOURCE: IRIDIAN TECHNOLOGIES

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Now you can be set to the same accurate time as the US military and the air traffic controllers. The people at G-Force have created a way for you to take advantage of the US Atomic Clock's accuracy. The G-Force watch receives a radio signal broadcast from the most accurate clock in North America. The government operates the F-1 Fountain Atomic Clock maintained by the National Institute of Standards and Technology in Boulder, Colorado. The clock will not gain or lose even one second over a million-year period. It is that accurate! The G-Force features atomic time with automatic Standard time and Daylight Saving Time adjustment. At all times, you can see the time display with a perpetual date and day-of-the-week setting. The watch has a large clear digital display. There is also an easy-to-find back-light button for reading the display when it is dark. The watch is water-resistant as well. It is rugged enough to take to the gym but handsome enough to wear to work and it is a great choice for those who prefer their watches to be practical and sharp-looking rather than overrated and overpriced.

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GOING AFTER MOM AND POP

If you want a good example of what's wrong with the U.S. patent system, just talk to Tim Beere and Cathy Brand-Beere of Fort Wayne, IN. This couple owns the quintessential mom-and-pop operation—DeBrand Fine Chocolates. The 15-year-old confectionery has three Indiana stores, and it also does a good deal of mail-order business over its Web site. Now, through no fault of their own, the Beeres are entangled in a disgraceful and costly patent fight that threatens to sour their otherwise sweet business success.

As Tim Beere recounts the bitter tale, one day last fall a local officer knocked on the door and served the couple with an unexpected lawsuit. The lawsuit, filed by a company the Beeres had never heard of, claimed that the Beeres' online chocolate business infringed two of its patents and demanded a $5,000 licensing fee if DeBrand Fine Chocolates wanted to continue selling products online. Beere says, "At first we thought it must be a practical joke."



But it's no joke. DeBrand Fine Chocolates is one of 50 unsuspecting small businesses, which in just the last few months have been sued by a San Diego outfit known as PanIP—short for Pangea Intellectual Properties. PanIP is a no-employees paper tiger of a company—technically, a limited-liability corporation—formed by self-proclaimed inventor Lawrence Lockwood to capitalize on several e-commerce patents he holds. With five rounds of lawsuits under way, PanIP finds and sues 10 to 12 additional businesses every month.

Lockwood's scheme has been diabolically simple. First, he garnered a couple of absurdly broad patents. Judging by the thousands of tangled and overlapping e-commerce patents that have been handed out in recent years, such patents are easy to come by. Next, he hired a tenacious lawyer, formed a company, and began filing lawsuits. Now, he picks his quarry carefully. Lockwood's attorney, Kathleen Walker, says her client merely wants recompense for the 20 years he has spent inventing. Ultimately, Walker says, Lockwood plans to sue "any and all infringers," a group that she admits could include just about anyone doing business on the Internet.

But there is little question about the kinds of companies PanIP has gone after. The lawsuits target small, successful, independent enterprises that do business on the Internet and are located far from urban corridors of power. DeBrand Fine Chocolates is a perfect victim. So is Delasco Dermatologic Lab and Supply, a skin care products company with fewer than 100 employees, in Council Bluffs, IA. Ditto for Can-Do National Tape in Nashville, TN; River City Meat Company in Kansas City, MO; and, in the latest round of PanIP lawsuits, Double "H" Western Wear in Salem, OR.

Did Lawrence Lockwood invent e-commerce? Hardly. Nonetheless, he is the rightful owner of exclusive rights to two e-commerce concepts: U.S. Patent 5,576,951, issued in 1996, covers an "automated sales and services system," and U.S. Patent 6,289,319 was granted in 2001 for an "automatic business and financial transaction-processing system." A close look at these patents suggests any number of strategies a competent patent lawyer could use to challenge Lockwood's payment demands. The latter patent, for example, despite its very broad language, explicitly claims rights to a system meant for filing loan applications online—a far cry from the purported infringements of the PanIP defendants.

But here's the rub: according to the American Intellectual Property Law Association, the average patent case that goes to trial costs defendants more than $1.5 million. Meanwhile, getting the U.S. Patent Office to reexamine even one of its more obvious mistakes is time-consuming and costly. Unfortunately—and this is really disgraceful—because they have little recourse, small companies such as DeBrand Fine Chocolates have considerable incentive to pony up the royalties. Two-thirds of the companies PanIP has sued to date have agreed to its royalty terms, says attorney Walker. Despite this grim reality, there is heartening news. Some 15 of the companies PanIP has targeted—including DeBrand Fine Chocolates—have decided to fight. They have banded together and started a legal-defense fund. "It has taken a lot of late nights," Tim Beere says.

Here's a way to make a quick buck: garner a broad e-commerce patent and demand money from small Internet businesses. Some will pay rather than defend themselves. It's time to help them fight back.

PanIP's request of $5,000 from DeBrand Fine Chocolates is less than the $30,000 PanIP sought from earlier defendants. Nonetheless, PanIP continues to file lawsuits, and Walker says her client is ready to fight "all the way through the courts to uphold our patents if we have to." It seems all but certain that many similar lawsuits are in the offing. And don't look to Congress for a remedy; there is no thoughtful legislation on the docket to redress the kind of problem the Beeres and other small-business owners face. It helps that in areas such as gene patenting, the U.S. Patent and Trademark Office has made the requirements slightly more stringent, but even that will do nothing to defuse the thousands of overly broad e-commerce patents already strewn about like ticking time bombs.

It's up to the courts to put the brakes on baseless lawsuits and prevent misuse of overly broad patents. And that is why I urge every reader to visit the PanIP defendants' Web site and learn more about their legal counterattack. The defendants' Web address might make you chuckle, but it should give you pause: www.youmaybenext.com. TR

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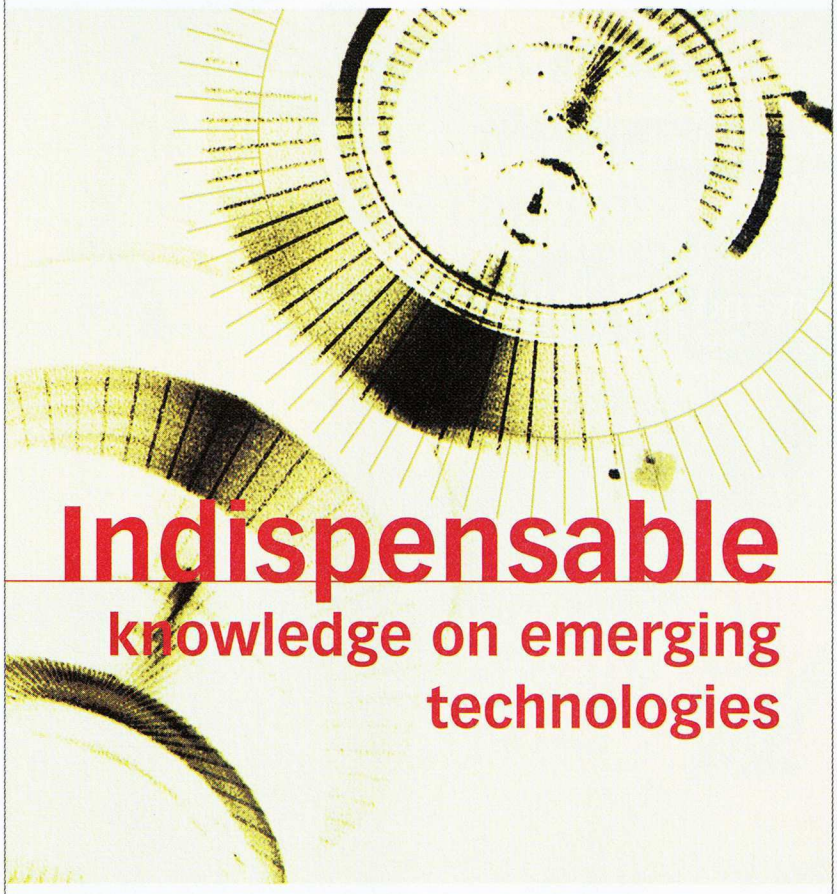
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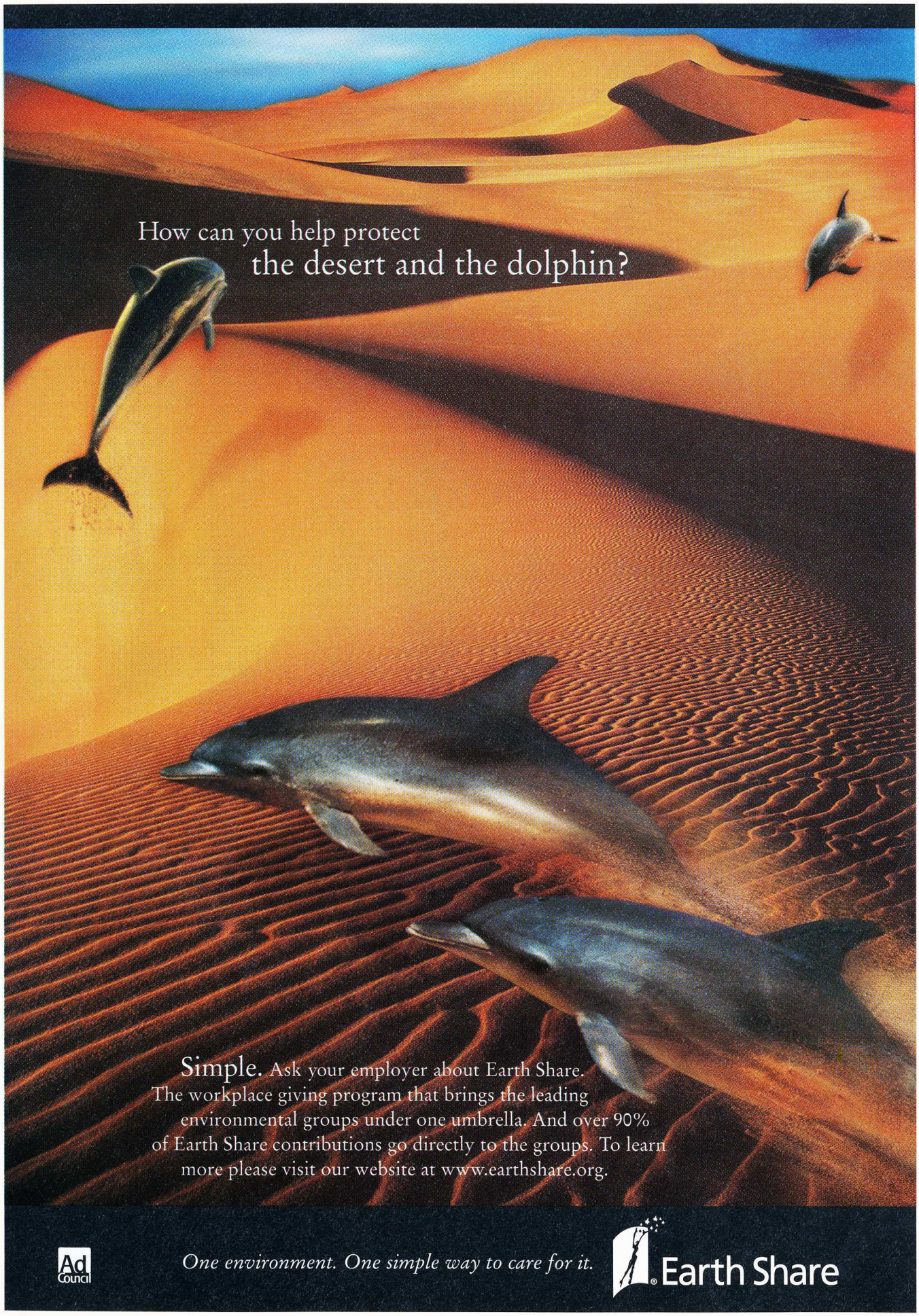
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Antenna Technology Breakthrough

First patented dish antenna brings in broadcast signals other antennas can't find.

The XiumAir's™ Spilateral technology conquers ghosts, fuzzy pictures and rooftop monstrosities.



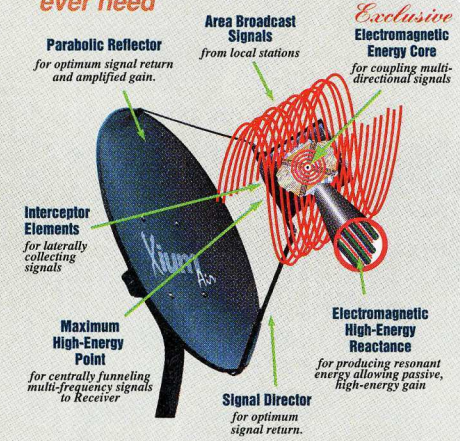
World's first dish-type TV antenna for great local reception

If you live in an area where TV reception is weak, 'rabbit ears' and ugly rooftop antennas may only bring in fuzzy signals that aren't worth watching. Enter the XiumAir Antenna -- the world's first spilateral antenna designed to bring in strong video and audio signals from all directions for great TV/stereo reception. Patented spilateral technology lets the XiumAir grab signals coming from all directions from as far away as 50+ miles. Its 18" parabolic reflective / ground element increases signal strength and stability to give you local broadcast reception as good as, or better than, cable TV or satellite reception. There's no expensive installation required, and it's fully compatible with any TV or stereo tuner for high-energy VHF / UHF / FM reception.

No aiming, rotating or tuning.

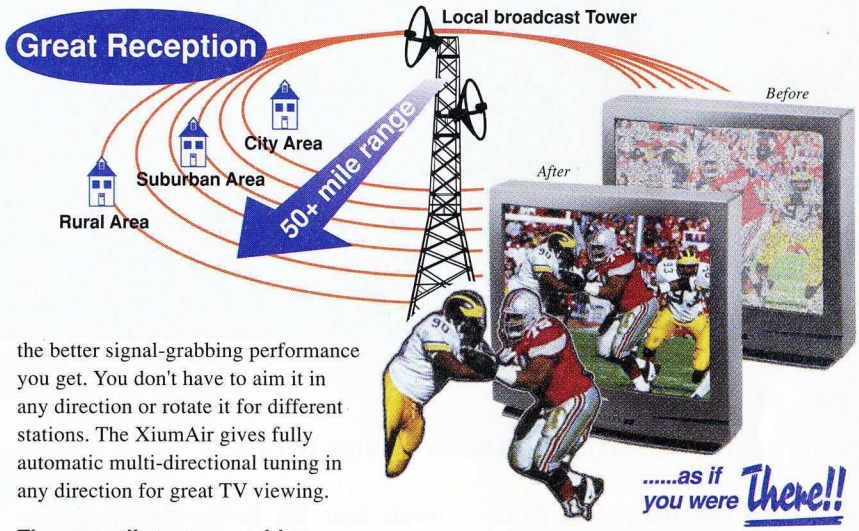
XiumAir's new 83-channel technology combines an all-in-one device for receiving high-energy TV reception. Unlike most external antennas, the XiumAir doesn't have to be pointed in the direction of transmitters. That's the beauty of spilateral technology. You can mount the dish-like antenna indoors or outside (on your roof or a horizontal mast). The higher the elevation,

The world's first dish-type TV antenna - the last antenna you'll ever need



XiumAir™ Works!

No matter where you live, the Xium spilateral "dish" antenna will collect all of the signals available, from any direction without the need for rotating or tuning.



the better signal-grabbing performance you get. You don't have to aim it in any direction or rotate it for different stations. The XiumAir gives fully automatic multi-directional tuning in any direction for great TV viewing.

The versatile antenna with many uses.

If you have a DSS satellite system, the XiumAir is the ideal complement for receiving local channels without monthly fees. And when high definition broadcast TV arrives in a few years, you will be ready. Plus you can use the antenna now for AM / FM stereo, home-based CB systems, and shortwave radio. The XiumAir Antenna features compact, modern styling that will blend in with almost any decor. The UV-protected housing is made of impact-resistant copolymer, making the exterior resistant to weathering and color change. It includes a standard cable connector for any cable-ready hookup. The XiumAir Antenna delivers maximum local broadcast reception to any television, stereo or any other audio or video receiver, without the use of unsightly, ugly or 'wind damaged' antennas.

Enjoy better TV reception - risk free!

This unique design is the result of years of research and testing, and now you can try it for yourself risk-free. Each XiumAir Antenna System is handcrafted and individually tested for high quality performance. With the XiumAir Antenna, you'll eliminate those unsightly antennas for good. The XiumAir Antenna comes with a 30-day manufacturer's limited warranty and Xium's exclusive risk-free home trial. If you are not satisfied for any reason, just call us for free expert installation assistance, or simply return it within 30 days for a full refund, less S&H.

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Leon Theremin, third from left, performs in a theremin-and-piano quartet.

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The theremin: electronic music's Soviet roots

Electronic instruments have found their way into almost every genre of music. While many may consider electronic synthesizers and musical computers phenomena of the digital age, the electrification of music dates back to early Soviet Russia.

In 1920 a young physicist, Leon Theremin (né Lev Sergeyevich Termen), was working at a technical institute outside St. Petersburg. One of his first assignments was to develop a device to determine how changes in pressure and temperature affect gas density. His creation proved so sensitive that even the wave of a hand would alter capacitance. By adding parts from radio transmitters, he was able to make such changes audible as warbling, whistling tones.

A former cello player, Theremin entertained his colleagues with simple tunes he played by maneuvering his hands near the device: the apparatus, originally called the aetherphone, was the first instrument that was played without being touched. Theremin demonstrated his device to Lenin in 1922 and later toured with it across Russia and Europe. The inventor brought it to New York City in 1927 and played for the cultural elite, including Sergei Rachmaninoff.

Theremin set up a laboratory in Manhattan, continuing his work and increasing the profile of the instrument with help from Clara Rockmore, a theremin virtuosa and fellow Russian. In 1929 RCA licensed and began producing his improved device, now known as the theremin. Much to the shock of his friends and family, Theremin disappeared under mysterious circumstances in 1938.

Over the next 20 years, interest in the theremin waned, but it was often heard in sci-fi movies. The instrument and its successors found new life in the 1960s, notably in the Beach Boys' "Good Vibrations." Robert Moog, a pioneering creator of electronic synthesizers, launched his career with a mail-order business selling his versions of the theremin.

Theremin reappeared in the public sphere in 1967, when a *New York Times* journalist happened upon him in Russia. The inventor had returned to his homeland, where he was made to serve time in prison and subsequently to develop military devices. He died in Russia in 1993.

The theremin recently experienced another revival—today hundreds of musicians, including Elvis Costello and the Imposters, use it. In his foreword to Albert Glinsky's 2000 book, *Theremin: Ether Music and Espionage*, Moog wrote that Theremin was "an object of adulation by thousands of modern-day music technologists." —*Lisa Scanlon*

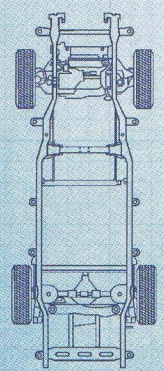
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